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A Study of the Principles and Methods of Improving Seed Corn (Maize)

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A STUDY OF THE PRINCIPLES AND METHODS OF IMPROVING SEED CORN (MAIZE)

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BY

SATYASARAN SINHA

THESIS

Submitted in Partial Fulfillment of the Requirement for the

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IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Agriculture

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CHAPTER I

INTRODUCTION

Indian corn is the farmers' best crop friend. Its foliage made of rippling leaves is excellent food for livestock, and its grain is good food for both man and beast. What a tremendous number of commercial products are made from it - Glucose is made for fruit preservatives, sugar for the schoolgirls' confectionery, syrup and corn-flakes for the breakfast table, corn starch for laundry, pearl starch for cotton and paper-mills, alcohol by fermentation, corn oil-cake for cattle feeding purposes, corn cobs for fuel, cellulose for smokeless powder, oil for paint, rubber substitute used in the place of crude rubber, husks for mattresses, etc. There is no other plant known in the world which yields so great returns for a given amount of labor. It is, therefore, known to every American farmer as "Corn is King". Indeed the improvement if this crop ought to be a matter of concern to every agriculturist, not only because of its general cultivation but because of its numerous by-products. Investigations show very clearly that the corn plant is quickly affected by the environment in which it is placed and yields readily to selection, so that the way for improvement is open to all, and if any one wishes he may make corn breeding a

vocation.

The writer passed several years in Behar where he got interested in raising bhootta (Hindoostanee work for maize). During the time of the last terrible famine in India, car loads of corn were shipped from the state of Illinois to save his countrymen from starvation. This circumstance led him to come to Illinois, which is the home of the prominent corn breeders to make a thorough investigation in the improvement of seed corn.

The knowledge of the subject of the improvement of corn has not been well classified; there are a few books, many scattered articles, numerous bulletins in English and foreign languages, and numerous statements in the writings of many men. It is hoped that the data presented in this paper may be useful wherever corn is grown.

America and Europe have given greater attention to improving plants by selection and hybridization than any other countries. Selection has been the keynote of success with many American farmers. They have"selected the best" for seed. The early Roman farmers too sought to improve their cereals by the careful selection of seed. Germany, as it is said, has increased her production of crops at least 25 percent. through the use of better seed alone. What is possible for them to do is also possible for us in India. By far the greater number of farmers in India are following the same crude methods of practice with regard to the selection of seed corn and cultivation of the crop that were in vogue fifty, and in many instances, one hundred years ago.

Nearly all the countries have produced breeders, but in India there is not a single farmer known as a plant-breeder. We find in this country that seed growing and breeding is a very profitable vocation. There is a great demand for well-bred seed corn, because it will always outyield ordinary seed and will flourish in the market. In India, the average yield of corn is many times lower than that of United States; this difference is in part due to better preparation of soil, but doubtless it is also due greatly to the selection and breeding of corn. There are two ways to increase the total yield in India; one is by planting more acres, the other is by raising more corn on the same acreage. Large yield and better quality depend on "good feeding", "good care", and "good breeding". By supplying these factors, it will be possible for us to improve the seed corn more profitably than it ever has been heretofore.

The Englishmen in India are introducing foreign varieties for the sake of curiosity. If we have similar climate and soil it may be that plant introduction will become a prominent feature. Adaptability is the first consideration in the selection of seed corn. Any variety can be adapted to the locality by selection through a number of years, but it is safer practice to plant that variety best suited to the soil and climate of India. If satisfactory native varieties are not to be obtained, approved new varieties may then be tested in a small way and gradually become acclimated.

Our practice should be, (1) to select our home varieties adapted to our native conditions, (2) to develop varieties by crossing and hybridization amongst themselves in order to satisfy

individual or personal desires. We hope that as the national demands are met the definite and special demands will become more distinct. From time to time a race of corn will come to be so markedly developed and of so much higher rating in India that foreign varieties will no longer be needed.

The principles and methods of improving seed corn, described in this paper, once understood, will not be difficult to put into practice. American farmers are doing this work, and have formed associations for mutual aid and in carrying it out. The farmers of India in maize districts could do much to arouse an interest in improving seed corn by using up-to-date methods.

CHAPTER II

ORIGIN AND HISTORY OF CORN

There are various accounts of the origin of corn. Some authorities claim that it is of Eastern origin, and that its name is mentioned in Chinese literature before Columbus discovered America. Harshberger[1] has refuted this argument and has shown that Southern Mexico is the original home. But the fact that ears of corn have been found in the mummies of Mexico and Peru is evidence these countries may have been its original home. Columbus found it growing in the Island of Hayti in 1492, where it was called Mahiz which is an Indian word. Some botanists say that Teosinte (Euchlæna Mexicana), a native Mexican grass, is its progenitor, which is called "Zea Canina" by Watson. Recently, Montgomery[2], has expressed a similar theory; he states "that corn and teosinte may have had a common origin, and that in the process of evolution the cluster of pistillate spikes in teosinte were developed from the lateral branches of a tassel-like structure, while the corn ear developed from the central spike. It is probable that the progenitor of these plants was a large much-branched grass, each branch being terminated by a tassel-like structure, bearing hermaphrodite flowers. As evolution progressed,

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[1] Harshberger, J.W.; Maize, A Botanical and Economic Study.

[2] Pop. Sc. Monthly. January,1906.

the central tassel came to produce only staminate flowers, these being higher and in a better position to fertilize the flowers on the lower branches. At the same time the lateral branches came to produce only pistillate flowers, their position not being favorable as pollen produces, while, on the contrary, they were favorably placed to receive pollen. This differenciation in the flowers was accompanied by a shortening of the internodes of the lateral branches until they were entirely enclosed in the leaf sheaths" as shown in Fig. 1.

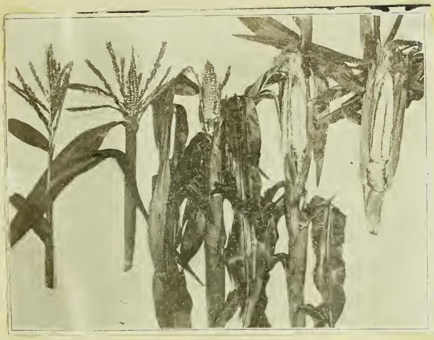

Fig. 1. Steps of Evolution of the Corn Tassel into an Ear.

(After Montgomery)

Bailey[1] experimented with Zea Canina and is strongly of the opinion that it is not a distinct species from our common corn,

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[1] Cornell Bulletin 49.

He mentioned that some varieties of sweet corn occasionally produce multiple rudimentary ears, and this Canina loses them under cultivation; all this evidence stands in favor of the theory of this close relationship. The tendency to sucker, to produce tassels on the ends of the ears, the abundant drooping tassels of the flint corn, and the occurence of all such pecularities in the aboriginal corn in the Azetic region indicate the relation that exists between the varieties.

The earliest explorers and colonists of all parts of the New World found maize, abundantly cultivated by the semi-civilized Indian tribes. It was one of their principal foods, hence it was named Indian corn to distinguish it from other cereals. There is no evidence that this crop was known to any country in the Eastern Hemisphere until it was introduced from America.

THE RACES OF CORN

The Polymorphic Species, Zea Mays, is divided into six distinct groups or races on account of their well-defined and persistent characters which admit of specific nomenclature; each of these groups have innumerable varieties due to culture in different climates. These groups are characterized by Sturtevant[1] as follows:

I. Zea tunicata, the pod corns. - In this group each kernel is covered in a pod or husk and the ear thus formed is also enclosed in husks. Reversion accordingly takes place in cultivated forms. The pod corn is excessively leafy, and the seed is rather hard and flinty, when planted it will usually produce podded and unpodded ears.

II. Zea everta, the pop-corns.- This group is characterized by the excessive proportion of the corneous endosperm and the small size of the kernels and ear. The best varieties have a corneous endosperm throughout, which gives the property of popping. The pop corn is more subject to sports than any other class. The seeds have strong vegetative power.

III. Zea indurata, the flint corns.- The corneous matter surrounds the sides and tops of the kernels, so that it is enclosed in a flinty coat, with soft, starchy substance in the central part. The kernel is usually about as broad as long, hard, smooth, and more or less oval. Flint corn, taking the plant as

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[1] O.E.S. Bulletin 57.

a whole, is somewhat smaller than dent.

IV. Zea Indentata, the dent corns.- In this group the sides of the kernels consist of corneous matter, the starchy endosperm reaching to the summit. By the drying and shrinkage of the starchy endosperm the summit of the kernel is drawn in or together, and indented in various shapes. The kernels are usually discolored, wedge-shaped and deeper than broad. Nearly all the corn grown in the corn belt belongs to this group.

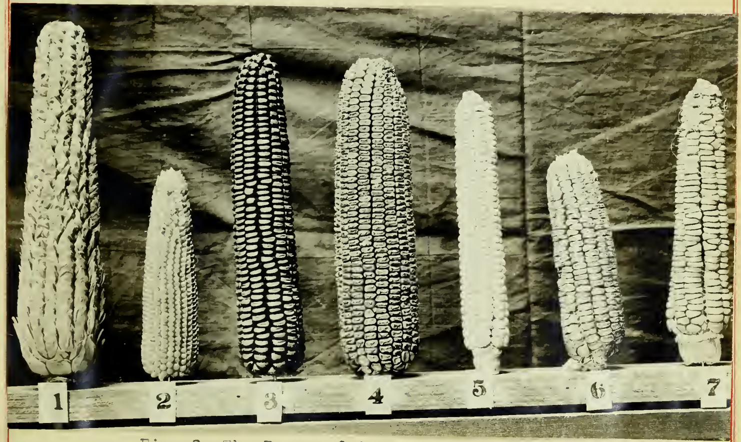

Fig. 2. The Races of Corn. 1.Pod Corn. 2.Pop Corn. 3.Flint Corn. 4. Dent Corn. 5.Soft Corn. 6.Sweet Corn. 7.Starchy-sweet Corn. (Original)

V. Zea Amylacea, the soft corns.- This group is recognized by the absence of corneous endosperm. Through the uniformi-

ty of the shrinkage in ripening there is usually no indentation, although this occasionally occurs. This is the mummy corn of Chili and Peru.

VI. Zea saccharata, the sweet corns.- The kernels consist of translucent, horny material, which contains considerable sugar instead of starch, and they are in a more or less crinkled, wrinkled, or shrivelled condition. This group seems less subject to monstrous growth than the others. It is extensively raised for cooking and eating while in the milk stage. It is extensively used for the canning industry.

VII. Zea amyleasaccharata, the starchy-sweet corns.- This is a group recognized by Sturtevant but it is of little importance. The lower half of the kernel is starchy, The upper half horny and transparent.

The above groups may each be divided into subraces , which in turn may be divided into an almost innumerable number of varieties. According to Sturtevant there are 507 varieties, but no complete study of them has yet been made.

CHAPTER III

BOTANICAL CHARACTERS OF CORN

Botanically, Indian corn is known as Zea Mays. It is an annual, herbaceous plant, belonging to the order, Gramineæ . It differs from other grasses in that its stem or stalk is solid instead of hollow.

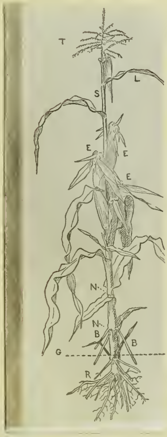

Fig. 3. Corn Plant. T,tassel; S,stems or stalk; L,leaf; E.E.E, ears; N.N, nodes; B, brace roots; R, earth roots: G,surface of ground. (After Sargent)

The roots are of two kinds, primary and secondary. The former is fine and fibrous. The corn plant has no tap root . When it nearly reaches its full height the secondary or the base roots come from the stem near the ground and help in holding the plant erect. Before these roots reach the soil they are covered

by a copious mucilaginous material, and when they reach the soil into which they penetrate they absorb water and plant food.

The stem or culm varies in height from 18 inches to 30 feet, according to the variety and conditions of growth. The stem is composed of smooth sections or internodes, joined together by thick joints called nodes. The internodes are flat or slightly hollowed out on the side where the leaf is borne. The mature stem has a pithy interior and a thin covering of the harder material.

Suckers or tillers often develop in hills of corn. They spring from the main stem near its lower nodes. They soon develop root systems of their own and are capable of independent existence. As a usual thing these suckers do not produce ears, rather they take plant food and water from the soil which should go to the building up of the main stalks; it is for this reason that the tillering habit of corn is usually considered not desirable.

The leaves arise from the nodes, there being a leaf at each one; they are arranged alternately. The lower part of the leaf sheath enfolds a portion of the stem, this leaf sheath is loose upon the internode, so that it makes room for the growth of the young ear. With the dent maize the number of leaves on a stalk varies from 12 to 18, with a width of blade from 3 3/4 to 5 1/8 inches.[1] Generally 16 or 18 leaves are produced in this climate, the lower ones die off before maturity, and the activity is confined perhaps to twelve.

Each leaf is divided into three parts - a sheath which is open along one side, a ligule, or membraneous outgrowth at the

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[1] Iowa Bulletin 2.

top of the sheath, and the blade.

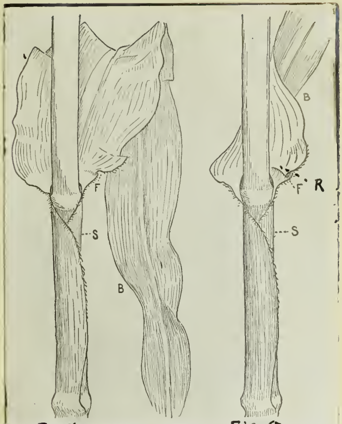

Fig. 4.

Fig. 5.

Fig. 4. Maize, leaf at rest. B,blade; S,sheath; F, a region of special fullness.

Fig. 5. Maize,with the blade (B) blown to the right and thereby twisted, and a deep fold made at F, thus relieving the sheath (S) and the stalk of strain. R, the rainguard. (After Sargent)

Just inside and springing from the ligule is a short, thin, yet rigid fringe which is held in close contact to the internode of the stem; this is the rainguard. The ligule is in such close contact to the stalk that the entrance between sheath and culm of rain water with dust particles is prevented, and the water runs back on either side on reaching the ligule.

If a section is made of the leaf blade, on examining with the microscope large wedge-shaped bulbiform cells are found in the upper epidermes; these cells when filled with water cause the leaf to unfold, and on hot days they dry out and cause the leaf to curl, thus the leaf blade prevents the high rate of transpiration.

The flower.- In corn the staminate (male or tassel) and pistillate (female or ear) are borne on the same plant, and at different places, so it is called monoecious.

The tassel is arranged in the form of a panicle of spikelets. There are two single flowers in each spikelet. Each single flower has its own set of inner glumes (D,E, Fig. 6) and

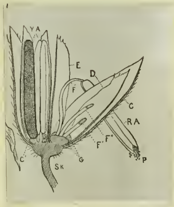

Fig. 6. Maize, A spikelet from the tassel cut lengthwise to show its two flowers, the one on the right fully open, the other not yet mature. SK,stalklet; C,C',outer glumes ("bracts"); D.E, inner glumes ("bracts") of the open flower; G, lodicules,which by swelling spread the glumes("bracts") apart; F'F'; filaments cut across; F,filament bearing ripe anther(R.A.); shedding pollen (P); Y A,young anthers, the left hand one cut to show the pollen. Enlarged.
(After Sargent)

the two together are enclosed by thicker outer glumes (C,C'). Each flower contains three stamens, mounted filaments (F) which are short at first, but when the anthers mature, they swing at the ends of long filaments. (See Fig. 7.)And thus the dry smooth pollen sacks or anthers are caught in the wind. The anthers are two-celled, they split up both sides. At the base of each set of these filaments we find the lodicules (G, Fig. 6) which by swelling spreads the glumes apart and allows the stamens to be pushed out. According to Harshberger[1] 2,500 pollen grains are formed in a single anther, and 18,000,000 are given as the number produced by each plant, there being 7,200 stamens to a panicle. Each pollen grain is very small containing a nucleus which is situated in the center, while the remainder of the cell is light, enabling it to be wafted by the currents of air. The pollen continues

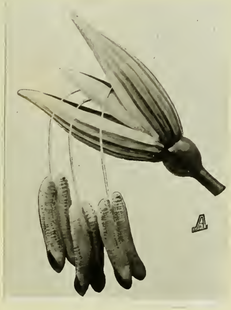

Fig. 7. A single (male) flower of corn much enlarged. (After DeVries).

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[1] Harshberger, J. W.; Maize, A Botanical and Economic study.

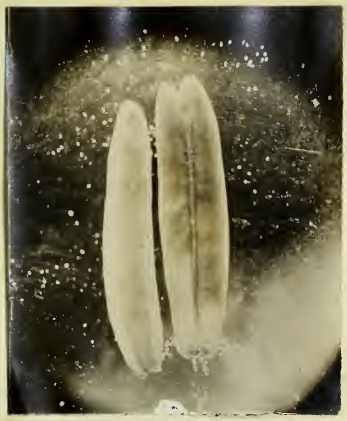

Fig. 8.Discharge of Pollen from the Anther. Enlarged.
(After ~~Hopkins~~). Shamel

to fall for about eight days, sometimes more and sometimes less. It first blossoms on the central spike of the tassel, and afterwards on the side branches, finally blossoming last on the lower part of the tassel.

The silk is found in the "shoot" or ear which is covered with husks or modified leaves. When the husks expand the silks jut out of the tip end; they are cylindrical, six to sixteen inches long and their ends are hairy (under the microscope). After a few days they appear in the open air, and each silk excretes upon the surface a mucilaginous substance which enables it to catch the pollen grains which fall upon the silk.

FERTILIZATION AND FORMATION OF KERNEL

The time at which the anthers and silks come to maturity

varies among different varieties and sometimes among different plants of the same variety. Sometimes the anthers ripen before the silks appear, sometimes the silks are receptive before the pollen is shed and sometimes the anthers and silks mature simultaneously. The grains of the pollen containing the male germ or nucleus fall or are carried by the wind upon the silk which leads to the female germ, the two nuclei thus brought together become fused, and as a result of this fertilization the kernel of corn develops.

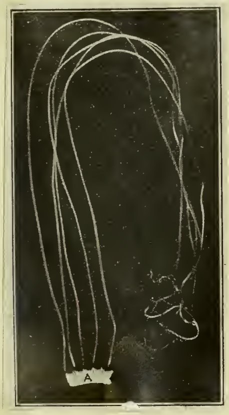

Fig. 9. One-half natural size. Five (female) flowers taken from an ear of corn. These were taken before they were fertilized. The kernels, (A), have not yet taken on a regular form. When fertilization takes place the pollen grain alighting upon the end of the silk (stigma) "germinates" and sends a tube down the stigma to the ovule (A). Here the two germs fuse and a kernel is formed.
(After Bull).

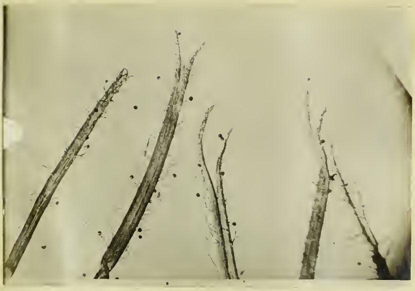

Fig. 10. Pollen-grains on the silks.
(After Hopkins)

No matter how many pollen-grains fall upon a silk, (see Fig. 10) only one causes the fertilization of the ovule. The silk dies as soon as the fertilization of the kernel has been brought about.

Nature has provided that the shedding of all pollen and sending out of all silks should not take place at one time. First, the early maturing anthers fertilize a few silks (stigmas) from the butt of the ear which come out first. This is followed by silks from the central part of the ear which appear as soon as the weather conditions become favorable. Then there is what may be called "full-bloom" of the tassel. Some days after this period the silks from the tip of the ear appear and secure pollen from the delayed anthers still holding pollen grains. This insures, for all practical purposes, a complete fertilization; thus an ear is formed.

On removing the husks carefully, we may observe that

each kernel has its own silk running from the crown of the kernel along the entire length of the ear.

CHAPTER IV

HISTORY OF THE CORN BREEDING

Before the discovery of America, the Indians of this country and the semi-civilized tribes of South America raised this crop ; their methods of breeding were crude. Improvement was started by the white men, but their progress was very slow at first. Among these early breeders, Mr. J.S.Leaming of Hamilton County, Ohio, began his work in 1826. He used to select from the ordinary yellow corn of his neighborhood toward a certain mentally fixed standard. He practiced this method for fifty-six years, after which it was taken up by his son, Mr. J.S.Leaming, Jr., who used to select by going through a field as soon as the husks began to ripen, ears slightly tapering from butt to tip, ears well filled over points, with straight rows, and ripening in from ninety to one hundred ten days.

In 1846, Mr. James Robert Reid, of Tazewell county, Illinois, brought a variety of corn known at that time as "Gordon Hopkins' corn", from Brown county, Ohio. He planted late in spring of 1846, and at harvest time he got a fair yield of immature corn. Seed was selected from this immature corn, and consequently the yield was poor in the following year. The field was then replanted with the seed of the Little Yellow Corn, and the missing hills were planted with a hoe. Since that time this corn has been greatly improved by selection. The characteristics

are unusually well fixed in all samples because of long and careful selection for fifty years. The original corn, with the small ears poorly filled out was changed to one of the most highly improved varieties of corn grown.

In 1876, Mr. James Riley, of Boone County, Indiana, began selecting from a large, coarse variety of corn grown in Boone County. He planted the seed in an isolated field and improved it by selection without crossing with any other varieties. He tried to remove the barren stalks by cutting out all such stalks before they produced pollen. After several years of selection, he gave this new type of corn a new name, Boone County White, and this is now the most popular variety of white corn in Indiana and Illinois.

In 1890, Mr. J.H. Beagley, of Ford County, Illinois, selected seed from a prize-winning exhibit of white corn. When sufficient corn was grown the seed was sold to an Iowa Seed Company which named it Iowa Silver Mine, and sold large quantities of it to the farmers of Illinois. Mr. Beagley "has selected toward a creamy-white color, cylindrical shape, tapering slightly at the tip, with an average of about eighteen rows of kernels. The variety has been developed by selection, no crossing or mixing of varieties having occured. The variety characteristics are strong"[1].

Little was done in a systematic way in the improvement of corn until 1896 when Hopkins discovered the "single-ear selection" at the Illinois Experiment Station with a variety of white corn locally known as Burr's White. His principle changed the whole system of corn breeding in the corn-growing states. He has

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[1] Myrick : The Book of Corn.

bred the individuality of ear not only for the physical characteristics of their kernels, but also for their chemical constituents which will be discussed later on. He convinced the farmers of Illinois of the great possibility of systematic selection and improvement of corn. This led to the organization of a society for the purpose of placing corn breeding on a business basis. The Illinois Seed Corn Breeders Association was founded in 1900, and its work started in 1901. Soon afterwards similar associations were organized in other corn-growing states, and soon the demand of selected seed developed amongst the American farmers. Many other experiment stations, such as Iowa, Kansas, etc., are bringing their work to the front rank. Amongst the private pioneers in corn breeding the Funk Brothers' Seed Company, at Bloomington, Illinois, has placed the selection of corn on a business basis.

REASONS FOR BREEDING CORN.

It is interesting to note what are the reasons for breeding corn. Hopkins in Bulletin No. 82 of the Illinois Experiment Station gives the following reasons for breeding corn for specific purposes:-

"It is a well-established fact that there now exist markets and demands for different kinds of corn. The price of corn varies, say from one-half to one cent per pound.'

"The cost of protein in the principal stock-feeding states varies from three to five cents per pound. In other words, the protein is several times more valuable per pound than the corn itself. Consequently stock-feeders want more protein in corn......

'The price of corn starch varies from two to three cents to five or even ten cents per pound, depending upon the wholesale or retail nature of the sale. The manufacturers of starch and of glucose sugar, glusose syrup, and other products made from starch want more starch in corn.

'In its own publication a large commercial concern, which uses enormous quantities of corn, makes the following statements:-

"A bushel of ordinary corn, weighing fifty-six pounds, contains about four and one-half pounds of germ,thirty-six pounds of dry starch, seven pounds of gluten, and five pounds of bran or hull, the balance in weight being made up of water, soluble matter, etc. The value of the germ lies in the fact that it contains over forty percent. of corn oil worth, say, five cents per pound, while the starch is worth one and one-half cents, the gluten one cent, and the hull about one-half cent per pound. It can readily be seen that a variety of corn containing, say, one pound more oil per bushel would be in large demand.

"Farmers throughout the country do well to communicate with their respective agricultural experiment stations and secure their cooperation along these lines.'

"These are statements and suggestions which should, and do, attract the attention of experiment station men. They are made by the Glucose Sugar Refining Company of Chicago, a company which purchases and uses in its six factories, about fifty million bushels of corn annually. According to these statements, if the oil of corn could be increased one pound per bushel, the actual value of the corn for glucose factories would be increased

five cents per bushel; and the president of the Glucose Sugar Refining Company has personally assured the writer that his company would be glad to pay a higher price for high oil corn whenever it can be furnished in large quantities. The increase of five cents per bushel on fifty million bushels would add $2,500,000 to the value of corn purchased by this one company each year. The glucose factories are now extracting the oil from all the corn they use and are unable to supply the market demands for corn oil. On the other hand, to these manufacturers protein is a cheap by-product, and consequently they want less protein in corn.

"Corn with a low oil content is desired as a feed for bacon hogs, especially for our export trade, very extensive and thorough investigations conducted in Germany and Canada having proved conclusively that ordinary corn contains too much oil for the production of the hard, prime bacon which is demanded in the markets of Great Britan and Continental Europe".

With the above purpose the systematic breeding was started at the Illinois Experiment Station and the results point out that the chemical constituent of the kernel was changed as it was desired, either to increase or decrease the protein, the oil or the starch. This also suggests the possibility of selecting for increased yield by following this same system. In fact this has actually been done at the Nebraska Experiment station where Montgomery improved a variety by means of this ear-row breeding system so that in four years the improved strain yielded over nine bushels per acre better than the original stock.[1]

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[1] Nebraska Bulletin 112.

CHAPTER V

METHODS EMPLOYED IN IMPROVING SEED CORN.

1. PRINCIPLES OF SELECTION.

1. Adaptability is the first consideration in the selection of seed corn. This is true as applied not only to varieties, but also to individual ears within a variety. When corn grown in one section of the country for a number of years is transferred to another section where climate and soil are different, the plant always undergoes more or less change during the first two or three years before it becomes adapted to its new environment and conditions. Davenport[1] sent a standard white Illinois corn, ripening in about a hundred and twenty days and giving yield of seventy-five bushels per acre, to be grown in Michigan, Wisconsin, Maine, and Mississippi. It failed to ripen in Maine, but at all other places it ripened in about a hundred days, producing short, inferior ears, or in other words, a worthless crop. The lesson to be learned from this is that one should select seed from the home locality. If satisfactory local varieties are not available approved new varieties may then be tested in a small way, and within a few years, they may become partially or entire-

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[1] Davenport, E: Principles of Breeding, 1907. P. 222.

ly adapted to local conditions.

2. Ideals: Every corn breeder must have a certain type as his ideal, so as to have always in mind the kind of corn he wishes to produce; then by selection he can bring this type close to his standard.

3. Purity: When a desirable variety has been found it is the duty of the breeder to take every precaution to keep it free from mixture. He should look after his plot when it is in bloom to see that his corn is kept free from mixtures. Strict adherence to a uniform color is essential in maintaining purity or freedom from mixture in any variety. Corn intended for seed should not be planted within a quarter of a mile of another variety of corn. A breeder should always purchase his seed in ears rather than shelled corn, so that he can see whether he is getting pure seed or not.

4. Vigor: It is a common practice to select ears at the time of husking, paying particular attention to the size and shape of ears, well-filled kernels, and a proper proportion of cob to grain. But this sort of selection does not take the vigor of the whole plant into consideration, perhaps the good ears were selected from undesirable or weak stalks. In order to secure the best results ears should be selected in the field, the main attention being given to the habit of growth, productiveness, vigor, etc., of the plant, as well as the characters of the ear, cob, kernel, and uniformity in ripening, etc.

5. Transmission; Breeders should always determine whether their seed corn is transmitting its desirable qualities,

and in case the offspring is showing any tendency to reversion, this offspring should be rejected and selection should be made again from the progeny of some other plant which has more completely fixed its qualities on its offspring. One should seek for the transmission of desirable hereditary qualities.

In all such cases where selection is the means followed for fixing desired characters, large numbers of individuals should be grown, thus offering the breeder a greater scope for selection and increasing the possibilities of securing the qualities sought. As soon as such qualities make their appearance the further improvement and fixation depend on continuous selection.

TIME OF SELECTION.

The field selection should be made as early in the season as the time of the first killing frost is anticipated. Farmers should not wait until the time of husking to select the good ears. Much of the seed planted in the spring turns out to be bad, not because it was not cared for during the winter, but probably because it was selected as the corn was husked, and had already bee killed or weakened by freezing. Every farmer ought to understand that freezing temperature will seriously injure his seed corn, especially when the corn contains a large amount of moisture. We often find two stalks of corn each bearing an ear of about the same size. One of them will have the husk turning brown showing maturity and ready for selection and picking, while the other ear will be found to be very immature, containing a high percentage of moisture, and unfit for seed purposes. One should select the

matured ear, and discard the other one. Farmers should not leave this work until it is time to fill the crib when it becomes impossible to tell which of the two ears matured first.

Selection of seed ears should always be made upon the plant when it is ripening in the field and never from crib or wagon. Williams[1] selected one lot of seed ears from plants growing in the field under normal conditions of stand, and another lot of the same variety and from the same field, but this time the selection was from the wagon. Eight tenth-acre plots were planted from the two selections, four plots of the plant-selected seed and four of the seed selected in the ordinary way.

The average of Plant Selection plots was 72.49 bu.per acre
" " "Ordinary " " " 69.26 " " "
Gain for Plant Selection 3.23 " " "

The only way a farmer can get the best crops is by planting matured seed corn from the best and earliest planted fields before the coming of frost, and selected upon the plant as it is ripening in the field.

The next point to be looked to in the selection of the seed is the character of the stalk that bears the ear. First, the most vigorous stalk should be selected, such that no ordinary wind will blow over or break down, and also one that fulfils the ideal of the breeder, as for instance, a stalk which stands erect, tapers well from base, bears a good ear rather low down, and a shank of medium length and strength, which allows the ear to droop

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[1] Ohio Cir. No. 71.

and therefore shed water, free from smut or other disease. Second, it should have a liberal growth of leaves, preferably 12 to 16, because it is through the action of sunlight upon the green leaves that the elements of soil, water, and air are transformed into the tissues of the plants. Therefore the leaves should be as large and healthy as possible in order to carry out their work to the best advantage.

The Character of the Ears: Where the corn is planted in hills ears should be selected from hills where there are two or more stalks, and never from a hill with a single stalk. Preference should be given to ears of cylindrical shape, well-rounded at each end, having the largest percentage of shelled corn to cob as well as kernels of the most uniform shape. The cob should be medium sized, lighter in weight, and of a bright and healthy color. The kernels should fit closely throughout their full length all over the cob. Straight-rowed ears, and ears with narrow sulci (a name given to the space between the rows of kernels) are to be selected.

Distance from the Ground to which the Ear should be Selected.

Chamberlain[1] says: "It is a general principle that the higher on the stalk the ear forms, the later the corn will be in maturing. This seems to be for the reason that the ear is fed through a series of tubes passing from the root up through the stalk. These series of tubes are in circles, one underneath or inside the other in the stalk. The outer tube or ones next to the

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[1] The Dakota Farmer, September 1,1910.

outside of the stalk terminate at the first joint. The next series of tubes terminate at the second joint, the third at the third joint, etc. When the plant begins to dry up at the top of the ground it dries just on the outside, and hence the circulation in the outer tübes is cut off first, at the second joint next, etc. If the ear forms at the fifth joint it is better fed by tubes well within the structure of the plant itself, and hence will be later in maturing and will generally grow larger than if formed at the first joint. For this reason we should not select our ears of corn for seed from too far up on the stalk. About the fourth joint is as high as we should select seed corn for central South Dakota, and probably in the northern part of the state it had better be selected from the third joint in the ordinary varieties of corn grown".

Smith's results at the Illinois Experiment Station also show that the early maturity is characterized by low ears. One of the greatest problems before the corn growers is that if maturity, a matter which can be more or less controlled by selecting with reference to the height of the ear. There is another disadvantage with high ear that makes husking in standing corn difficult, and if large, they overbalance the stalk and cause it to lodge.[1]

Selection of Long Ears Vs. Short Ears.

Experiments in this line have been conducted by Williams[2]

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[1] Illinois Bulletin 132.

[2] Ohio Bulletin 212.

showing that the long ears outyielded the shorter with a gain of 3.97 bushels in yield which is the combined average of twenty-two tests on forty-four tenth-acre plots during the years 1905 to 1909.

In his experiment with Filled-Tipped Ears Vs. Bare-Tipped Ears, the three years' average gain for filled-tips was 1.07 bushels per acre.

In his further experiment with Heavy Vs. Light Seed Ears the heavier ears in its ear-row tests outyielded the lighter during the years 1904 to 1906. Bringing this report down to 1909 these tests continue to tell the same story, the average gain per acre for heavy ears during the years 1908 and 1909 was 1.93 bushels. The highest yield resulting from heavy and large seed has been found to hold true not only with corn but also with wheat, rape, root crops, etc.

Selection of Seed Corn From Different Parts Of The Ear.

Several experiments have been conducted, one at Georgia Experiment Station[1] giving the following result:-

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[1] Georgia Bulletin 34.

Parts	Yields per acre bushels of shelled corn.
2 inches of butts	26.86
2 inches of middles	26.24
2 inches of tips	27.34 (Highest)

Another at Wooster, Ohio[1], the following result is the average for nine years:-

Parts	Yields in bushels.
Butts	56.86
Middles	59.27 (Highest)
Tips	53.70

The third one at the Arkansas Experiment Station[2]. The result is as follows:-

Parts	Yields per acre in bushels.
Large end (i.e. butt)	34.2 (Highest)
Middle	30.8
Small end (i.e. tip)	30.6

From the above data we find that the highest yield was obtained by selection from the tips at Georgia, from the middles at Ohio, and from the butts at Arkansas. The results are different at three different stations. There is not sufficient evidence at hand to justify the rejection of either butt or tip or middle kernels. It may be said that there is no advantage in planting seed from any special part of the ear, provided nearly equal stands are obtained. It is better to give more consideration to the characteristics of the plant as a whole than the characteris-

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[1] Ohio Bulletin 78.

[2] Arkansas Bulletin 22

tic of any particular part of the ear from which the seed is taken.

Selection of Kernels having Large Germs.

It has been proved that the germ of seed is much richer in fat than the other parts of the kernel. It is also very rich in protein. Selection of kernels having large germs consequently richer in nitrogen has been strongly urged by some writers as a practicable method of increasing the percentage of proteids. Probably greater progress can be made in this direction however by taking into consideration the relative proportions of horny and starchy parts of the kernel as pointed out by the Illinois Experiment Station Bulletin 87. "Plants from kernels having large germs are more vigorous, have more plant energy, and are stronger and hardier in every way."[1]

Broad Selection.

By broad selection we mean the making of composite samples, this system is generally known to the farmers as broad breeding. This can be accomplished by selecting many ears from widely distributed plants in large fields, and then mixing the shelled corn before planting. Much of the main improvement of maize may be attributed to this system of increasing and maintaining fertility and vigor which are hereditary characters.

Selection By Score Cards.

In picking out ears to plant, one of the best guides

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[1] Maryland Bulletin 106.

that we find in making such selection is the score card. The following score card is adopted by the Illinois Corn Growers' Association:

Points	Perfect Score
1. Uniformity of exhibit	5
2. Shape of ear	10
3. Length of ear	10
4. Circumference of ear	5
5. Tips of ears	5
6. Butts of ears	5
7. Kernel uniformity	5
8. Kernel shape	5
9. Color in grain and cob	10
10. Space between rows	5
11. Space between kernels at cob	5
12. Vitality or seed condition	10
13. Trueness to type	10
14. Proportion of shelled corn to cob	10
Total	100

The variety that is scored highest is selected for planting. The values given in this score are temporary, and may be changed from time to time as the crop is improved. This score card can not be adopted to every locality or state. The points and the scores generally vary with the score cards of other states simply because of the demands of the public and the way the improvement is made.

Selection After Germination.

Early in the spring the ears thus selected should be tested for germination. Five kernels are to be removed, taking one from the butt, three from various parts of middle portion, and one from near the tip on the ear. They should be placed in numbered rows in shallow boxes of moist sand, divided with squares, arranging them so that the kernels from ear No. 1 are placed in square No. 1, etc. A damp cloth is spread over the kernels, and it should be left in this condition for five or six days in a warm place where the temperature does not fall lower than 50 degrees F. Then the seed corn (corresponding with the number) which germinates earliest and strongest are to be selected. Seed corn with a percentage of germination below 90 can not be recommended for planting.

Selection Index Numbers.

There is another method of selection which has been lately proposed by Pearl and Surface[1] of University of Maine. "An "index number" in the sense here used means a single mathematical function which combines in itself the values of several independent or correlated variables. In such a function each of the variables may be weighted in any desired manner to meet the needs of particular problems. Having decided the relative degree to which each variable should be weighted, the index number as finally calculated gives an absolutely impartial and impersonal summing

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[1] American Naturalist Vol. XLIII. No.511.

up of the total combined value or effect of the variables entering into it".

The idea of selection index numbers was applied in breeding sweet corn (Zea Mays Saccharata). The actual index number used for this corn has the following formula:-

$$I = \frac{A + 3B + 2C}{D + E + F^2}$$

The meaning of the letters used in the above equation is explained as follows:-

A = Length of ear multiplied by the circumference of the ear. This gives a measure of the absolute size of the ear.

$$B = \frac{100 \text{ x wt. of shelled grains from tip and butt}}{\text{Total weight of shelled grains from whole ear}}$$

B is the percentage which the grain on tip and butt is of total grain on the ear. This gives a measure of the extent to which ends of the ear are covered with grain.

$$C = \frac{100 \text{ x circumference of the cob at the middle of the ear}}{\text{Circumference of ear at middle}}$$

$$D = \frac{100 \text{ times the weight of the cob}}{\text{Total weight of shelled grains from the whole ears}}$$

E = (circumference at butt) - (circumference at tip). A measure of the shape of the ear.

F = 100 - (the observed percentage germination of grain from the ear used).

All such measurements and determinations are made on the thoroughly dried ear and are recorded in centimeters and grams.

This selection index is in one way a supplement to a score card described beforehand. It affords a means of shorten-

ing the whole information which the score card gives into one 'unit! The variety that totals the highest value of the index is selected for planting. We think that the above formula can also be applied for selecting any variety of corn. With our previous score card the individual score can be increased or decreased as the crop is improved,and emphasis is put on a particular point, so it is with this selection index number, the breeder can substitute "2 B"in place of "3 B" or "1 C" in place of "2 C", thus making it convenient for using as a score card.

2. TESTING PROMISING INDIVIDUALS FOR PREPOTENCY.

When a breeder selects an individual, after an elimination of poor inheritance, he thereby gives prominence to those individuals possessing strong inheritance of desirable characters- in other words, prepotency. It is frequently found that two selected ears of corn are not equally prepotent. In the offspring of one almost every plant may possess the inheritance of desirable characters such as heavy yield, while in the offspring of the other only a few of the plants may possess the inherited characters to a limited degree. To test the prepotency it is necessary to grade carefully the offpsring of each promising individual, and this is the primary reason for planting the offspring of different individuals in the ear-row tests or in separate rows. By this sort of planting the breeder can see the characteristic difference of individual ears. Then at selection time he should watch whether his seed corn has transmitted the desirable charac-

ters of the stalk from which it was taken, and also whether the qualities of the seed ears themselves reappear in the ears harvested. The various kernels within an ear may possess individualities that are transmitted to their offspring.

3. AVOIDING IN-BREEDING BY CONTROL OF PARENTAGE.

Darwin proved by a long series of experiments that cross-breeding is beneficial, and that continued in-breeding is injurious to the species. He summed his conclusion in the famous dictum, "Nature abhors perpetual self-fertilization"[1]. In-breeding is desirable with many of our cultivated plants, as for instance, tobacco where we want uniformity in every respect, but in case of corn it is injurious. The injurious effects of in-breeding with corn were recognized even by a number of primitive tribes who have the methods of guarding against it. The Indians in the regions of Quetzaltemango, in Western Guatemala, and the Hopi Indians of Arizona adopted methods of planting seeds of more than one local variety in each hill in order to secure larger yields.[2] Shamel[3], in his work with the in-bred corn in comparison with the ordinary or naturally cross-fertilized, points out the following data:- 1. Weakened germinative power. 2. Increased number of bar-

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[1] Darwin: The Effect of Cross and Self-fertilization in the Vegetable Kingdom.

[2] Plant Industry Bulletin 141.

[3] Illinois Agriculturist, p.26, 1898.

ren stalks. 3. Tendency of Stalks to lean and later in season to fall over instead of standing erect. 4. Later maturity. 5. Smaller ears. 6.Increased tendency to decay in ear and stalk. 7. Tendency to produce variegated leaves. 8.Greatly increased height, size of stalk, width of leaf and total amount offoliage"(?)".9.Easily and seriously affected by hot, dry weather. 10.An almost incredible decrease in yield. He further found that in four generations of continuous self-fertilization the vitality of the seed became so weakened that the seed failed to germinate.[1] Collins[2] reports that a few generations of self-polliration usually results in sterility. Webber[3] reports loss of weight and decrease of ears with his in-bred corn. He had seeds of Hickory King, produced by the pollen of the same stalk, which gave a yield the next year at the rate per hundred stalks of forty-six ears, weighing nine and one-third pounds. When he crossed the seeds of the same race with different seedlings, this time the yield under the same conditions was at the rate per hundred stalks of eighty-two ears, weighing twenty-seven and one-half pounds.

He further reports loss of vigour and almost sterility in attempting to fix the hybrids of Hickory King X Cuzco. He inbred some ears with pollen from the stalks bearing them, while others were pollinated with pollen from other hybrid seedlings of the same parentage. When the hybrids of the second generation

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[1] U.S. Dept. Agri. Year Book, 1905 p.388.

[2] Plant Industry Bulletin 141.

[3] Science N. S. Vol XIII No. 320.

were in-bred with pollen from the same stalk, there was indicated a great loss of vigour, the plants being small and almost totally sterile; while those produced from seed which was crossed with pollen from a different seedling were much more vigorous and productive.

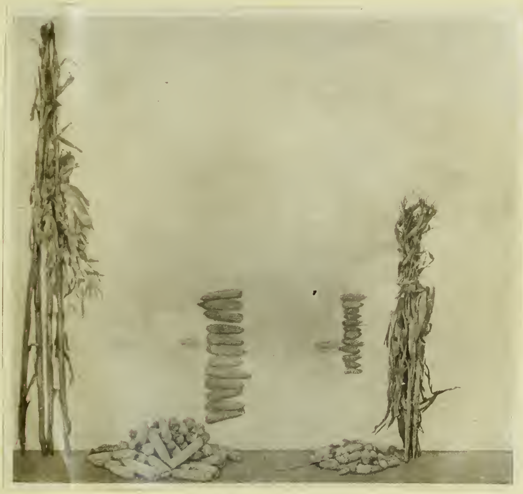


Fig. 11. A Contrast in Corn.
That to the right, ears hanging on the floor, and standing, is self-fertilized; that to the left is from ordinary fertilizing - by the wind - the same amount of seed being used in both cases. (After Harwood). [illegible]

The belief that in-breeding results in decrease of yield and loss of vigour is to be strongly impressed upon the minds of farmers and breeders, who should use some methods that will avoid

close in-breeding. The authors of Bulletin No. 100 of the Illinois Experiment Station give direction for the prevention of in-breeding in which it is recommended to plant by the row-system, i.e., seed from a single ear in each row, and to detassel every alternate row. Selection of seed will be always from the best-yielding detasseled rows. This method of breeding by row-system will be discussed in a later chapter.

4. CROSSING.

In Burbank's methods variation plays the most important part, and obtain variation large numbers of crosses are often made. But this is not necessary in corn, as the tendency to variation is already great. But when it is necessary to combine the desirable qualities of two variations in one plant, then comes the question of crossing or hybridization. By crossing we will not only get all kinds of combinations but a chance to pick out the most desirable ideal type discarding thousands of undesirable and imperfect plants.

Selecting for Crosses.

Crosses or hybrids may be made by artificial or hand pollinating, (1) selecting superior plants in two separate stocks in carefully planted nurseries; (2) selecting plants in a nursery where the two varieties are planted in alternate rows; (3) selecting plants in two ordinary fields, either near together or far apart from each other. In all such cases selection should be made

in order to combine in the new cross or hybrid certain valuable characters of different races.

Steps before Hybridization.

During the season of 1910, the writer crossed several varieties of corn. From the study of this work the following directions were compiled:-

Go over the field, select the desirable corn plants wherein the tassels have come out and are not shedding pollen, bag the first young shoot (i.e. the undeveloped ear) which is just coming out of the axis of the leaf and in which the silks have not yet appeared. In this case a tough paper bag (8 or 10 pound grocer's sack) may be drawn over the shoot and pinned closely around the stalk. Pin carefully so as not to pass through the ear but just outside of the shoot. Examine the work from time to time. On hot days the shoots grow so rapidly that the paper bag may burst, so it is advisable to adjust and repin them in allowing their growth. Care should be taken not to keep the bags loose, otherwise insects may get in under their edges and carry pollen to the silks and thus make them fertilized. In the same way another bag is placed over the tassel of the other variety from which we desire to obtain pollen. Then fold the bottom of the bag around the stalk and pin it tightly. If possible leave a fold of the bag in such a way as to make a small pouch below which will collect the pollen as it is shed from the anthers.

When the silk reaches a length of two or three inches, the ear is ready for pollination. The bag of the ear is removed temporarily protecting the ear from other pollen by the apparatus

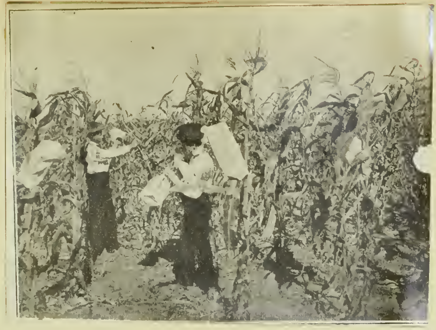


Fig. 12. Bagging the shoots and tassels of corn in hybridization work. (After Miller).

as shown in Fig. 13. This apparatus is made of five square wooden pieces in form of a box, open end being down and encircled with

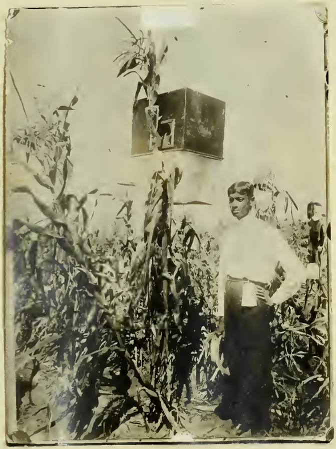
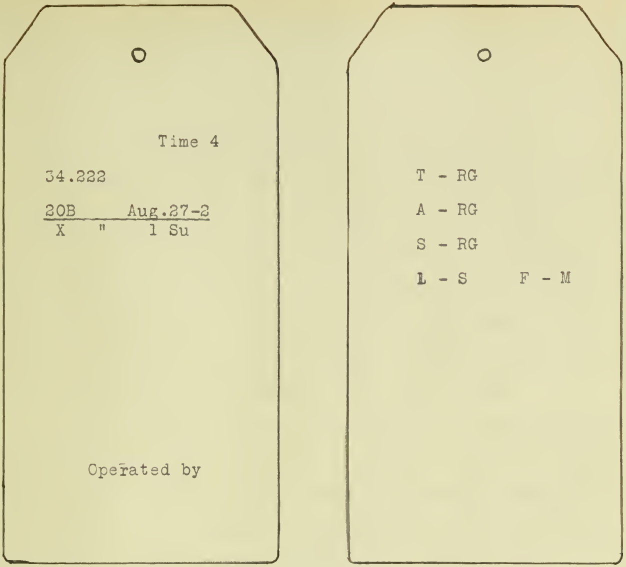


Fig. 13. Ready to remove the bag of the ear and dust pollen over the silk. (Original)

cloth hanging loose; the whole thing is supported by an iron rod to which it can be adjusted to any height of the ear by means of a thumb screw. Arrangement has been made so that at the time of performance light would be secured through two pieces of window glass, one in the top and another in the front side.

The pollen from the bag containing the tassel is dusted over the silks of the ear from which the bag is just removed. Care should be taken that every silk receives, at least one pollen grain; if any particular silk receives no pollen, or infertile pollen, no kernel will be found to have developed at the base of that silk, and consequently a poorly filled ear will result. We find very often such ears in artificially pollinated corn after removing the husk, and this is one of the ways in which this can be accounted for. Further care should be taken not to dust too much pollen and also that the cloth of the apparatus, which might have been contaminated with other pollen, does not touch the ear. Shake the shoot right after the application of pollen. In many cases one application of pollen will be sufficient, some recommend two or three such applications in order to have the ear pollinated perfectly. It depends greatly on care of manipulation as well as upon weather conditions.

When this is done the bag should again be drawn over the shoot and tightly pinned in order to prevent contamination from foreign pollen. The pollinated ear should then be carefully labelled with a tag made of moderately heavy paper upon which any records which may be desirable to make may be written as shown below:-



Crossing Side of the Tag

Description of Female Parent written on the other side of the Tag

Fig. 14.

(Note. "T" stands for tassel, "A" for anther, "S" for silk, "L" for laminæ, "F" for foliage or leaf).

The bag should remain over the pollinated shoot until the silks are all completely withered and all danger from further pollination from foreign pollen is passed. This will be about twoto three weeks. In case it rains hard before the withering of the silk or just after the pollination, and if the bags be torn by storm, it is better to clip the silk just a little and then

draw on a fresh bag. Great care should be taken to protect from contamination.

Influence of Weather on Pollination.

Weather condition has much to do with the fertilization of flowers. Warm, sunny weather, with a slight breeze is ideal. A heavy dew and misty atmosphere will with-hold the progress for several hours but as soon as the sun shines, it will return to a good condition. With the exception of early evening about five o'clock, the period of greatest activity of pollination is usually in the early morning from sunrise until ten o'clock.

With adverse weather conditions the fertilization of flowers may be delayed, and if such weather lasts for a long time, the sex germs may lose their strength and finally result in a very poor fertilization. During the past season the writer examined some of the crossed ears at husking time. Because of not getting the pollen on at the right time, or other causes, some of these ears produced partially filled kernels. The complete fertilization of the flowers greatly depends upon the continuance of good weather and a careful pollination.

The classes of corn, as dent, flint, pod, pop, sweet, and flour corn can be intercrossed with perfect freedom. The ear of the corn may be crossed readily by pollen from its own stalk and sucker, as by the pollen from another stalk. Hartley says: "It makes no difference whether the pollen be taken from the main stalk or its sucker of a particular plant for breeding"[1].

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[1] Proc. A.B.A. Vol II p.144.

Value of Hybrids.

In many cases crossing distinct sorts increases the size and vigor of the offspring, and good qualities of the two varieties are formed in the hybrid. We know that the seed of a hybrid inherits characteristics not only from the ovule-bearing parent, but from the pollen-bearing as well. McClure[1] reports that the corn grown from hybrid seed was in nearly all cases clearly increased in size. As to the yield he adds further: "It seems that cross-bred corn gives larger yields at least for the first and second years after crossing than an average of the parent varieties, but how long this greater fruitfulness will last is undetermined".

East[2] in his crosses on well fertilized land found very striking results. He crossed a white dent No. 8 yielding one hundred twenty-one bushels per acre (at 70 pounds per bushel) with a yellow dent No. 7 which had been in-bred artificially for three years, yielding sixty-two bushels per acre. The cross or the hybrid yielded one hundred forty-two bushels per acre. He crossed again a Longfellow No. 34, an eight-rowed yellow flint yielding seventy-two bushels per acre, with the same No. 8 white dent, yielding one hundred twenty-one bushels per acre. In this case the hybrid yielded one hundred twenty-four bushels per acre. He crossed another Sturge's hybrid (a twelve-rowed, yellow flint X a tall, low-branching stalk partaking of the character of dent

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[1] Illinois Bulletin 31

[2] American Naturalist Vol XLIII No. 507

varieties) with the said No. 8 white dent. The flint parent yielded forty-eight bushels per acre, while the new cross yielded one hundred thirty bushels per acre. It is true that the land was well-fertilized, and this had its effect upon the yield, but it must be admitted that the increase in vigor over the parents in all those cases was greatly due to intelligent crossing.

Beale[1] in his investigation along this line reported that the pure seed yielded 57½ pounds in the ear; the "crossed seed" yielded 69½ pounds in the ear. In other words, the crossed stock exceeded the pure stock as 121 exceeds 100, nearly. Five cases reported by Morrow and Gardner[2], gave increase over the average of the parents running from 1.9 percent. to 28 percent, with an increase average of 14 percent. Shull[3] by first in-breeding and then crossing got an increase over the original mixed stock of 2 percent. Collins[4] crossed primitive types with one another and with United States varieties; he reports increased yields in 14 out of 16 cases, the average increase being 53 per cent.

The fact that increased yield can be obtained by crossing two varieties has been certainly established, yet the practice has not been applied on a commercial scale, as it ought to be. Because the increase in vigor and yield is the main point for breeding corn we should improve our seed corn by intelligent cross-

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[1] Report Mich. Bd. of Agri. 1881-2 p.136.

[2] Illinois Bulletin 25

[3] Proc. A.B.A. Vol V, 1909. p.54.

[4] Plant Industry Bulletin 191.

ing or hybridization. By selecting varieties which give increased yields uniformly when crossed and crossing these for seed corn it seems that the average yield can be greatly increased.

5. MUTATIONS.

Mutation is the term applied by DeVries to express the origin of species. It is considered by him the most important factor in the process of evolution. Early in the middle of the eighteenth century Linnaeus devised the present system of classifying plants and animals. He used two names, a species and a generic name. He believed that his species were the units of nature and were created as such in the beginning. He recommended Sub-divisions of Species which he called "Sub-Species" or "Varieties". The "varieties" which are later called "elementary species" by De Vries remain more or less steady in their characters from generation to generation, breeding true in artificial conditions. Cultivated plants as well as wild ones are composed of such "elementary species", and each cultivated variety contains hundreds of sharply defined types of "sub-species", which are distinct from one another in botanical characters. Many of our best varieties of wheat, oats, fruit,and other crops have been secured by the separating and breeding of these "elementary species" of cultivated plants. From the primitive age down to the present this selection has been maintained, though unconsciously even by savage races. By this means mutations, which, in wild nature, would have disappeared forever, have been preserved to become the progenitors of our cultivated crops.

The idea of organic evolution reigned also in the mind of Lamarck. He developed a theory of evolution which states that the characters acquired during the lives of individuals are inherited . After him followed Darwin who offered the "Theory of Natural Selection" to explain the origin of species. Darwin recognized individual variations or "fluctuations" and "definite" or discontinuous variations or "sudden-jumps" or mutations. He believed that new species were formed by the accumulation of favorable variations. In his works on "Animals and Plants under Domestication" he gives further a long list of "Spontaneous variations" or "Sports", many of which he fully believes were the starting points of new and constant varieties, and it can be believed that some of such mutations appeared before the animals and plants were domesticated, suggesting to us the directions in which their breeding operations should be managed.

According to Hartley[1] in corn,mutations occur frequently; the instances of sudden departure from its previous bounds or change of character along any line transmitted from generation to generation are common. Such mutations are more frequent along undesirable lines than along the line of productiveness. When they occur along the line of productiveness, as they do on a carefully conducted breeding plot, they ought to be preserved and "shaped up" and "finished off" by isolation and continuous selection.

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[1] U.S. Dept. of Agri. Year Book 1909. p.314.

6. XENIA

The immediate effect of pollen has long puzzled many botanists. Focke[1] proposed the term "Xenia" which is the supposed immediate or direct action of foreign pollen on parts of the mother plant external to the ovules. De Vries[2] attributes this phenomenon to double fecundation. Correns and Webber with their studies on Xenia in maize comes also to the same conclusion. The phenomena stands thus:-

We all know that when a blue corn, for example, is crossed with a white corn, there is a union of the characteristics of the two varieties. When the kernels containing the hybrid embryos are planted, they produce some white, some blue, and some mixed kernels , as would naturally be expected. What has so long been a mystery, however, is that in the same season in which the crossing is done, blue or mixed or spotted kernels appear in the ear of the white corn. Fecundation is generally supposed to take place in the germ. How then do these outside parts of the embryo become affected? To quote Webber[3] for the explanation of this phenomena:-

"The nuclei which form the endosperm reproduce free in thecytoplasm of the embryo sac, the cell walls which delimit them not forming for some time, probably not until nearly the ultimate number of nuclei have been formed. Before a very large number is

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[1] Focke, W.O: Die Pflanzen - Mischlinge p.511,1881.

[2] De Vries: Sur la fecondation hybride de l'albumen. Comptes rendus d. Seances d. l'Acad.d. Sci.T.129,pp.973-975. 4 Dec.1899.

[3] Division Vege. Physiolo. and Patholo. Bul.22. pp 34-35.

formed they move out from the center of the embryo sac and usually come to lie near the wall, where the nucleus reproduction continues. In the delimination of the nuclei later by the formation of walls about them, the process of wall formation begins at the periphery of the embryo sac and gradually extends inward. This process of endosperm formation which is common in seed plants and is known to occur in wheat, is doubtless the process occuring in corn. If, then, the union of the second sperm cell with the embryo sac nucleus fails to take place and they both divide separately, when the nuclei, formed by their division move outto the surface of the embryo sac the nuclei of male and female origin become more or less interspersed. In their further division we would then have groups of cells of male origin here and there, interspersed between those of the female origin. It is probable that when the nuclei become dispersed around the outer portion of the embryo sac they largely retain their individual location and sphere of influence, so that the nuclei resulting from the division of one nucleus after it has assumed a location at the surface remain near together and, ultimately, when delimited by walls, form a group of cells derived from the nucleus. If this is the case, whenever a nucleus derived from the division of the second sperm nucleus is located, after migration to the periphery of the embryo sac, there would be formed ultimately an island of tissue which, being derived entirely from the male parent so far as the nucleus is concerned, would probably exhibit almost entirely the characters of the male parent. This hypothesis would account forthe occurence of variegated kernels.....

"When the migration of the nuclei from the centre of the embryo sac to the periphery occurs, if the nuclei derived from the male nucleus have remained grouped together, as would probably occur, while those derived from the division of the embryo sac nucleus have remained grouped together in a similar manner, it is probable that in their migration to positions near the periphery of the embryo sac those from one group would come to occupy mainly one portion of the embryo sac, while the others would occupy the other portion. This would lead to the production of kernels where approximately half of the endosperm resembles one parent and the other half the other parent", as he found in some crosses.

He states further that those cases of supposed xenia where the pericarp is affected must be due to other causes or be explained as errors of observation.

According to Kornicke[1], Xenia is shown in the aleurane layer of the endosperm, the portions of the kernel outside of the endosperm remaining unaffected. Correns reports that this influence shows in the endosperm, all parts outside of this remain entirely unaffected, and it extends only to the color of the endosperm and the chemical composition, size and shape of kernels remaining uninfluenced.

The immediate effect of pollen is found in all varieties but more frequently in sweet and pop corn than in others.

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[1] Körnicke, Friedr. Vorläufige Mittheilungen über den Mais. Sitzungsberichte d. niederrheinischen Gessells.f. Nat. u. Heilkunde in Bonn,1872,pp. 63-76.

Whether this is shown in the color of the endosperm or not, and whatever may be the case it is not good practice to plant for seed any ear possessing mixed kernels, even if all the kernels not true to color have been removed, since the influence of the previous cross pollination may at any time display itself in the following generation.

7. MENDEL'S LAWS.

These laws were discovered by Gregor Mendel, an Austrian priest, in 1866. Before we proceed to explain how these laws help in improving seed corn we wish to state them in a general way.

1. The Law of Dominance: When two plants having some pair of contrasted characters (such as yellow field corn and white sweet corn) are crossed, one only, the dominant character (i.e. the smoothness of field corn) appears in the first generation. The other (the wrinkled) which does not appear in this generation is said to be recessive. The following is a partial list of dominants in corn breeding:-

Flint dominant to sweet
Flint dominant to dent
Dent dominant to sweet
Purple dominant to no purple or white
Yellow dominant to no yellow or white
Red dominant to no red or white

2. The Law of Segregation: Whenever there occurs a pair of contrasting characters of which one is dominant to the other, in the second generation when this hybrid is inbred it splits up into three kinds: There are one-fourth recessives which will continue to breed true to the recessive character, there are one-fourth dominants which will breed true to this type, and are therefore pure. The remaining half will have the dominant character which may be called impure, since in the next filial generation when in-bred their offspring will again split in the proportion of three with the dominant characters to one with the recessive or absent characters, or in other words there will be 75 percent. of the individuals which will show the dominant character, while 25 percent. will show the recessive character. These 25 percent. will ever after breed true, because they contain nothing but the recessive character; while of the 75 percent. showing the dominant character, one-third which are pure dominant will breed true, and the other two-thirds having the hybrid characters will again split in the next generation.

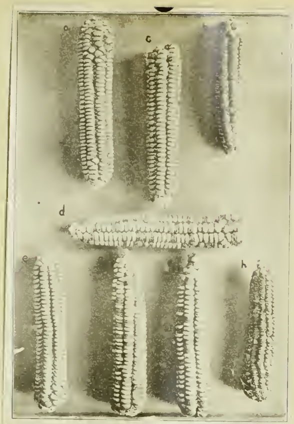

Fig. 15. Mendelian Segregation in Maize. a and b, the two parents, starchy and sweet maize; c, the first hybrid generation showing dominance of starchiness; d, the second hybrid generation show-segregation with the ratio of three starchy to one wrinkled seed. Lower row, daughters of d, e, f, and g, results of planting starchy seeds. One ear out of the three is pure starchy. h, result of planting sweet seeds. Ear is pure sweet.
(After East)

Mendel suggests that the cause of these peculiar phenomena is that a hybrid plant whose parents differ in a single character pair produces two kinds of egg-cells and two kinds of pollen-grains, one kind being like those of one of its parents, the other kind like those of its other parent. Taking as an illustration a hybrid of sweet corn, having sugary endosperm, with field corn, having starchy endosperm, when the germ cells were formed a segreagtion of the two potentialities representing the two contrasting characters would occur, and we would have germ

cells of one kind containing the potentialities of sugary sweet corn and the other containing the potentialities of starchy field corn. This segregation or purity of germ-cells takes place in the formation of both the egg-cells and pollen-grains. We thus find two kinds of egg-cells and two kinds of pollen-grains in the first generation of the hybrid.

In the above hybrid we have spoken of two kinds of pollen-grains, one of which is identical with the pollen of the sweet corn and the other with that of field corn, the real difference between them was that one of them produced starchy and the other did not, the one that produced starchy is dominant, and it is because of a stronger determiner meeting a weaker determiner in the germ. In the starchy corn there may be a certain organ which performed its function, while the corresponding organ in the sugary corn failed in this. Hence we say that in the former the stronger determiner was present corresponding to the "presence hypothesis", in the latter it had weaker determiner corresponding to the "absemce hypothesis". This explains the cause of one producing yellow and the other white etc., as well as of one being starchy and other sugary or whatever may be the case in question.

Several botanists experimented to determine the occurence of definite segregation in maize. Emerson[1] states that definite segregation occurs in maize. Lock[2] investigating heights

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[1] American Naturalist, 44 , 739-748, 1910.

[2] Lock: Studies in Plant Breeding in the Tropics, III, Experiments with Maize. 95-184.

of maize plants did not find segregation. East[3] in his recent experiments with maize 'has shown unquestionable segregation in size characters by comparison of the F_1 and F_2 generations'. Some of these segregates will breed as true as the parent forms. For practical purposes in corn breeding the fact of segregation is of greatest importance because the segregates will breed true.

3. The Laws of Recombination: So far we are dealing with one character pair or monohybridism. Now we are going to discuss di-hybridism, when two or more "pairs" of characters are present in the same hybrid, these pairs are independent of each other, so that one member of a given pair may be transmitted with either member of another pair. If we cross yellow sugary corn with white starchy corn we can foretell what will occur. Since yellow and white as well as sugary and starchy are antagonistic characters of allelomorphic pairs, yellow will be dominant over white, starchy will be dominant over sugary. Let us represent Y for yellow, s for sugary, w for white, and S for starchy.

By crossing Ys X wS we will get heterozygote YswS, and by further development we will have egg-cells of four combinations, namely,Ys, wS,YS,ws. In the formation of pollen grain we will have the same combination of potentialties, as in the egg-cells, namely, Ys, wS, YS, ws, so far as these two character pairs are concerned. When these are brought together which is a matter that depends on laws of probability, we get sixteen possible combinations to produce second-generation hybrids as shown in the following table:-

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[3] American Naturalist, Vol. XLV. No. 531, March 1911.

Table I.

Gametes of female.	Gametes of male.			
	Ys	wS	YS	ws
Ys	YsYs	wSYs	YSYs	wsYs
wS	YswS	wSwS	YSwS	wswS
YS	YsYS	wSYS	YSYS	wsYS
ws	YSws	wSws	YSws	wsws

In the above we find that some of these matings are alike, and striking out them we will have nine different combinations of which

9 contain both Y and s i.e. Ys

3 contain w but not s i.e. wS

3 contain S but not w i.e. SY

1 contains neither Y nor S, i.e., ws

And this is the 9 : 3 : 3 : 1 ratio which we have in the case of di-hybridism, whenever we deal with two allelomorphic pairs. Out of these sixteen combinations only four will breed true in future generations. From this F_2 generation only one (i.e. Ys Ys) out of nine Ys, only one (i.e. wS wS) out of three wS, only one (i.e. YSYS) out of three SY and the only one ws will breed true without any further selection and the rest will not breed true, but will split in future generations.

We are now in a position to state the law of recombination as follows: In the second generation of a hybrid all possible combinations of the characters of the original parents tend to occur. Further, if the second generation is numerous enough, all

such combinations will occur in some individuals in homozygote form and being thus firmly fixed will reproduce true to seed.

Fixation of Hybrids.

In hybrids we try to combine the desirable qualities of the two different varieties, discarding their weak points. In many cases they combine, and in few cases they reverse to the parental types. Now the question comes how to fix the good qualities when they do combine. Those varieties that bear the recessive character can be kept pure by self-fertilization without the strict isolation from the variety bearing the dominant character. Those varieties that bear the dominant characters can also be kept pure by self-fertilization. We have shown that inbreeding causes deterioration, but in such cases when a breeder wants to keep his variety pure and breed true, he will have to inbreed.

In case of an intermediate hybrid, that is, one in which the two characters of a certain pair are blended the fixation has been possible. Halstead[1] has bred into a fixed race the intermediate color of a cross between black Mexican sweet corn with Egyptian by selection. Webber fixed a hybrid of black Mexican sweet corn having the blue-black kernels with Stowell's Evergreen which has a nearly white kernel, into a race of light blue violet color. He got this after four years' continuous selection of such intermediate light blue violet kernels for planting, and by

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[1] Proc. A.B.A., Vol. IV. p. 350.

isolating the patch[1]. In fixing corn hybrids he suggests in another paper to cross different hybrid seedlings having the same characters, rather than in-breed a hybrid with its own pollen, then to plant the seed of such selected hybrids in isolated patches, so that the hybrids will not be crossed[2].

The time required to fix a hybrid varies from two to several generations. Punnett[3] says: "Two generations suffice to produce and fix the new variety, and one further generation is all that is required to indicate the fixed individuals".

Practical Importance of Mendelian Facts.

The breeder knows that no plant is perfect, every plant is a composite of thousands of characters. From this point of view there may be as many undesirable characters as desirable ones. The breeder seeks for a strain that will be uniform in appearance, that will breed true. He may want entirely new characters as well as recombinations of old ones, he has definite ideals, and wants to'work to a line'. It seems to us that all these can be fulfilled by the application of Mendel's laws of hybrids which suggest what we are to look for, and the best ways of combatting difficult problems; hence these laws have a great value in improvement of corn.

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[1] Bailey: Cyclopedia of American Agriculture,Vol.II,p.67,1907

[2] Science N. S. Vol. XLIII. No. 320.

[3] Punnett: Mendelism. p.60.

CHAPTER VI

COMMON METHODS OF CORN BREEDING.

1. EAR-ROW AND PEDIGREE BREEDING.

We have explained before the necessity of testing promising individuals for prepotency, and this can be done by planting the individuals in the ear-row test. In this way we may study the variation of the progenies of individual corn plants, growing side by side, and their ability to produce bushels of corn per acre, by determining the record of the progenies of individual ears.

Size of Ear-row Test Plot: The best number of ears to use has not yet been decided. Montgomery recommends to start with not less than 100, and better 200 ears. Williams uses 25 ears. At the Illinois Experiment Station where corn breeding has received special attention for the past fifteen years the authors of the Bulletin No. 100 believe that 96 ears is a safe number to use, so far as in-breeding is concerned. There are several conflicting factors in using a larger or smaller number of ears. The breeder will make better selection of seed for the next crop with the smaller number of ears,but there is less chance of finding one possessing especially high producing power. Then again, with a very small number of ears, there is some danger of evil effects from too close in-breeding.

Location of Plot: The plot should be situated in an isolated position. If such a position is not available, the plot may be planted in the center of a large area of the same variety but should be at least half a mile distant from any other variety of corn.

Selection of Soil: Soil should not be exceptionally rich, but only of the average fertility of the region. The land should be level or of uniform slope, and so laid out that all rows should be equally affected by tile drains, surface ditches, dead furrows, etc. If some part of the plot be higher than the other the rows should be planted so that each will have an equal amount of high and low land. Great care should be taken for the uniformity of soil conditions in the rows otherwise the whole tests become unreliable.

There are three methods most generally used to avoid self-fertilization and too close in-breeding. The first one is suggested by Hopkins and his associates, the second one by Williams of the Ohio Experiment Station, and the third one by Hartley of the United States Department of Agriculture. There is not very much difference between these three methods, the theory being the same. The first two methods are worked out in the most scientific way. The last one is the simplest and generally suited to the farmers.

First Method[1]

Ninety-six ears are selected from the general field at the beginning, later the breeding ears should be selected from the

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[1] Illinois Bulletin No. 100.

highest yielding rows in the previous season's ear-test. Ears are numbered 1 to 48, and 51 to 96 omitting numbers 49 and 50. Ninety-six rows are planted with the seeds from each selected ear, the row should be given the number borne by the ear which is planted in it. Every alternate (i.e. the even numbered rows) are detasseled. The best four ears from each selected field row are chosen; two of them are used to produce "sire seed" or "sire-rows", the remainder to produce "dam seed" or"dam-rows", in order to obtain the greatest degree of cross-pollination. The seed plot is divided into four equal parts, the even numbered rows (i.e. those which are to be the "dam rows") are planted in each quarter with ears from the selected rows in that quarter; but the seed for the odd numbered rows(i.e. those which are to be the"sire-rows" or pollen supplying plants) with ears from the selected row of another quarter of the plot. The plan adopted is to plant twenty-four rows in quarter No. 1 with the sire ears from quarter No. 4, in quarter No. 2 with sire ears from quarter No. 3, in quarter No. 3 with sire ears from quarter No. 1, and in quarter No. 4 with sire ears from quarter No. 2. This totals ninety-six rows. It should also be noticed that there is a definite sequence of planting which is as follows. For the even-numbered rows, 2,6,10,4,8,12,2,6,10,4,8,12; for the odd-numbered rows, seed comes from rows 76,80,84,78,82,86, 78,82,86,76,80,84. The six numbers 2,4,6,8,10,12 are used as representing the actual numbers (in their succesive order) of the rows from which the selected ears were taken. In alternate years, the sequence for the odd-numbered rows is altered by changing the place of the two sets of six figures; the sequence for these ears being 78,82,86,76,80,84,76,80,84,78,82,86. In this way the blood lines

are continually kept as far apart as is possible.

All the rows should be of the same length, they should be at least 100 hills long, but they may well be 40 rods long. It depends upon the amount of seed one wishes to put in. The rows are to be planted three feet apart, with two or three kernels dropped every 36 inches. If found convenient a corn planter may be used in dropping the kernel, provided care is taken to see that the box is perfectly cleaned out after each row is sown, and before the kernels from another ear are placed in it.

(Note: For the next year's breeding plot seed is taken from the six best yielding detasseled or even-numbered rows in each quarter, from ears being taken from each selected row, thus making a total of 96 ears for the next year's breeding plot).

Propagation Plot: In this plot the seed taken from the selected rows of breeding plot which is not used is planted. It may include also the remnants of seed corn which was not required for the breeding plot. It is considered desirable to detassel every alternate row.

Commercial plot: The seed from this plot should be only the best obtainable seed corn from the propagation plot. Here it is also desirable to detassel every alternate row. The seed from the detasseled rows is distributed as best seed,and that from not detasseled as second best seed (possibly at slightly lower price). It is sometimes called the "increase field" because it is used to increase the quantity of well-bred seed produced in the breeding plot.

Registering Corn and Pedigree Breeding.

As soon as any ear is selected to be planted in a breeding plot, it is given a "Register Number" which represents that particular ear only and for all time. For this purpose a certain system of numbering is used by which can be shown the ear number and at the same time the year of its breeding or the number of its generation and the field row in which it was planted. This is done by starting the first year in the 100 series, numbering the ears to be planted in succession from 101 to 148 and 151 to 198, and the second year starting the 200 series, running from 201 to 248 and 251 to 298, and so on, starting each succeeding year with a higher hundred.

The Illinois Experiment Station uses a corn registering blank, a copy of which is given on the following page:-

CORN REGISTER

Breeder ____________

Variety____________ of ears planted and rows harvested Distance between hills ___

Strain ________ in season of 1911. No. of hills in row _____

Description of Individual seed Ears. Performance record of rows.

Register No.	Dam No.	Annual Ear No.	Length of ear.	Tip circumference of ear.	Butt circumference of ear.	No. rows of kernels.	No. kernels in row.	Wt. of ear.	Wt. of cob.	Tip circumference of cob.	Butt circumference of cob.	Percent protein in grain.	Percent oil in grain.		Planted in field row No.	Corn lbs per row.	Corn bus. per acre.	No. of ears in row.	Percent protein in grain.	Percent oil in grain.
		Average																		

Average yield multiplying plot (Year 1911
(Year 1912

Average yield commercial field (Year 1911
(Year 1912
(Year 1913

In this blank the "Dam Number" which is placed in the second column, is the "Register Number" of the parent ear, it helps in tracing the pedigree record from year to year back to the source.

Annual Ear Number - Each selected ear from the field is given an "Annual Ear Number" which runs in a series from 1 up to 300 or more. This number is only temporary, to help while making the final selection of seed ears, and then when the time comes to plant selected seed ears, each is given a permanent "Register Number" as explained before. In this way various descriptions of each ear together with the performance record of field rows, etc. are carefully preserved.

Second Method[1]

In this method each ear-row test is duplicated, and also the so-called standard row or uniform check row is used. Williams selects 25 ears, and plants them in order in the breeding rows, using only one-half of the kernels of each ear. Sixty-one rows will be required, 11 of which will be checks. No matter how carefully the land is selected, it may lack uniformity, and for this reason check rows are planted with a uniform lot of corn. Starting with a check, every sixth row throughout the test will be planted as a check, in this way the check rows will be 1,7,13,19,25,31,37, 43,49,55, and 61. It should be noted that the selected number of

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[1] Ohio Circular 66.

ears for planting on the check rows are shelled and kept separate, and the same number of hills (and kernels) planted from each check ear upon each check row. The remaining rows 1 to 50,exclusive of the checks are planted with the 25 ears to be tested, two rows from each ear, row 1 and row 26 being planted from ear 1, 2 and 27 from ear 2, etc. The rows are usually 50 hills in length. The plot will begin and end with a check row. Notes regarding the number of plants, rapidity of growth, height of ears are recorded during the growing season. At harvest time the total yield of each row of a duplicate ear-row test is taken.

The Value of the Check Rows: The check rows perform the service in correcting the yields in the ear-row work. The method of determining the yield is the same in each case. Whenever we see any variation in the yield of check rows, when compared with the variation in yield of the individual ears, it would be easily understood that certain ears have proved their ability to produce much more bushels per acre than other ears of this test; this variation in yield is largely due to differences in soil because the check rows are six times as far apart as the other rows. Actual yields depend upon environment and go and come accordingly; comparative yields depend upon heredity.

Williams[1] suggests a plan for continuous corn breeding, by which the record of preformance of both male and female parents can be secured and a reliable pedigree is thus established. As shown in the accompanying diagram, in the first year the ears for the ear-row test are selected from the general crop (G.C.). Those

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[1] Ohio Circular 66

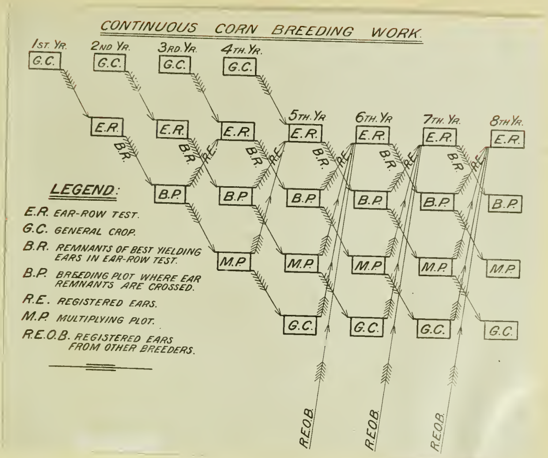
CONTINUOUS CORN BREEDING WORK.
1ST. YR.
2ND YR.
3RD. YR.
4TH. YR.
5TH. YR.
6TH. YR.
7TH. YR.
8TH YR.
G.C.
E.R.
B.R.
R.E.
B.P.
M.P.
R.E.O.B.
LEGEND:
E.R. EAR-ROW TEST.
G.C. GENERAL CROP.
B.R. REMNANTS OF BEST YIELDING EARS IN EAR-ROW TEST.
B.P. BREEDING PLOT WHERE EAR REMNANTS ARE CROSSED.
R.E. REGISTERED EARS.
M.P. MULTIPLYING PLOT.
R.E.O.B. REGISTERED EARS FROM OTHER BREEDERS.

Fig. 16. (After Williams).

ears are given duplicate ear-row test the second year; and the third year, the remnants of the four highest yielding ears of the ear-row test of the second year are planted in the breeding plot (B.P.), detasseling all the plants grown from one ear in each plot. By saving the seed only from the detasseled rows, a direct cross is made between two of the best ears upon the other two selected ears. In the fourth year ears from each of these crosses are again crossed in a multiplying plot (M.P.) by planting in alternate rows and detasseling the even-numbered rows. In this system the ear-row test plots are not detasseled. To describe this work further the writer takes the liberty of quoting Williams.[1]

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[1] Ohio Circular 66, p.11.

"Each year will have its own ear-row test, the ears tested in the ear-row test of the third year all coming, as before, from the general crop. In the ear-row test conducted the fourth year of the work, registered ears from the third year's breeding plot meet the selections from the general crop of the same year. One is thus enabled to test out the results of his breeding work to date. No pedigreed ear is carried from one breeding plot to another simply on the reputation of "pa" and "ma". Those registered ears must go back to the ear-row test, climb the high fence, and, if they succeed they will be found in the breeding plot of the fifth year. No ear gets into any breeding plot in this system of breeding which has not demonstrated its worth. Of every ear produced in any breeding plot, it is possible not only to name the sire and dam but to give the performance record of sire and dam, and that record, comparatively speaking, must be a good one. Take, for instance, the breeding plot of the eighth year. Of some of the ears found in this plot it will be possible to give the performance record of the sire and dam as tested in the ear-row test of the seventh year; of the grand-sire and grand-dam as tested in the ear-row test of the fifth year and of the great grand-sire and dam as tested in the ear-row test of the third year; and if there are other ears there with a shorter pedigree it will be because they have demonstrated their superiority over those of a longer pedigree.

"As the work continues the ear-row test will draw upon the multiplying plots for testing, and, after the fifth year, from a general crop which has descended from pedigreedears".

Third Method.

In this method seed is also planted by the ear-to-row method, each half of each row is detasseled to prevent in-breeding from one end to the middle, alternate ends of adjoining rows being detasseled as here illustrated. The dotted lines indicate the half of each row detasseled:-

Row 1 . . . D . . . ____T____

Row 2 ____T____ . . . D . . . .

Row 3 . . . D . . . ____T____

Row 4 ____T____ . . . D . . . .

and so on. It will be seen that the seed formed on the detasseled row are cross-fertilized with individuals of the tasseled rows. In the next year if the seed be selected from Row 1, it will be numbered 1-1, 1-2 and so on; it is advised to write all such numbers on the stakes placed at the end of corresponding rows.

A composite sample is made of ears used in planting the breeding rows, and this is used to plant several border rows around the breeding plot to protect the breeding ears from foreign pollen and also from depredations of crows, squirrels, etc.

Detasseling.

We have placed much emphasis upon detasseling alternate rows in the breeding plot. This is to be done to prevent inbreeding and consequently to favor cross-breeding which increases the vigour and yield of succeeding crops. Detasseling is accomplished by pulling tassels as soon as they show plainly in the top of the stalks and before pollen is shed. Care should be taken not to

injure the plants, and also not to cut the tassels, but instead they should be allowed to grow to their limit; then separating at the top joint by a careful pull. Pulling the tassels from the stalks before they shed any pollen entirely prevents self-pollination. In order to perform their work thoroughly, the rows will have to be gone over every two or three days at tasseling time, as the tassels are not all in the same stage of development.

Several Experiment Stations have published their results on detasseling corn which are summarized in the following table:

Table II

Name of Station	Total No. of tests.	Crop increased.	Crop decreased.	No effect.
Cornell	4	3		1
Delaware	2	2		
Georgia	1	1		1
Illinois	2		1	1
Kansas	3	1	1	1
Maryland	1		1	
Nebraska	2		2	
Ohio	2		1	1
S. Carolina	1	1		
Utah	2		2	
Total	20	8	8	5

What can we infer from the above results? We observe the direct physiological effect, but the effect on the progeny is not here considered. It is from this latter effect that detasseling is strongly recommended by breeders to prevent any possible danger of in- breeding.

Barrenness.

It is also advised to detassel all weak, inferior, barren and suckering stalks of the breeding plot, otherwise the pollen of those stalks will fertilize good ears of good stalks, and by hereditary tendency make them also inferior, as well as tend to increase the percentage of such stalks in the field. Barren stalks are those that fail to produce seeds. De Vries noticed barren stalks which neither produced ears nor tassels; and as a rule this barrenness is hereditary. It is therefore on this account that they should be eliminated.

There are several factors related to barrenness:-
1. It is greatly affected by climatic conditions, with cool days and nights the amount of barrenness will be increased. 2. The soil has its influence; if the soil be dry during the time the ears are forming, there will be more barren stalks, whereas with a fair amount of moisture there will be a less percentage of barren stalks. With light soils which are not suited for growing corn, a large percentage of barren stalks will be produced. 3. It is directly affected by the rate of planting: At the Nebraska Experiment Station[1] six percent. of the stalks when planted at the rate of one to the hill were barren, while the proportion reached as high as twenty-seven percent. when planted at the rate of four stalks

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[1] Nebraska Bulletin 91

per hill. That a very large number of barren stalks result when corn is planted so thick is due to the fact that the soil is unable to supply enough plant food to maintain the stalks and at the same time produce ears. 4. Weakened seed; seed having low germinative power will produce barren stalks. The data in the following table illustrates this matter very well, being taken from results at three county stations in different parts of Iowa[1]:

Table III

	Strong seed				Weak seed		
Ear No.	Germination S. W. B.	Stand	Barren	Ear No.	Germination S. W. B.	Stand	Barren
49	6 - 0 - 0	74.3	1.9	50	4 - 0 - 2	74.8	3.2
25	6 - 0 - 0	75.2	.6	9	2 - 4 - 0	75.7	6.3
28	6 - 0 - 0	77.1	.0	40	4 - 2 - 0	77.1	4.9
34	6 - 0 - 0	78.1	1.8	37	4 - 2 - 0	79.1	4.8

Collins[2] does not advise the elimination of barren stalks; he thinks that this results in increasing the percentage of self-pollinated plants. He writes:- "It is impossible to distinguish the truly barren plants at the time of tasseling. ..... Some of the plants which eventually prove to be the most prolific show only small rudiments of ears at the time of tasseling. The continued removal of such plants results not in the elimination of barren stalks, but in the elimination of the plants which possess

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[1] Bowman and Crossley: Corn, p. 450.

[2] Plant Industry Bulletin 141.

a valuable adaptation to avoid self-pollination." De Vries strongly favors the elimination of barren stalks. He draws conclusion from experimental evidence by saying that "the detasseling of barren stalks is always only a half-measure, the rejection of the entire rows being the only reliable process"[1].

Suckering or Tillering.

The habit of suckering or tillering is common with corn. Botanically, a sucker is simply a lateral branch arising from one of the lower nodes or joints of the corn plant. The young sucker is at first attached to the main stalk and draws its nourishment from it, but it soon develops its own roots and may become separated from the main stalk and live independently. A sucker may or may not produce an ear. It seldom does, however, altho a tassel is generally present.

There are various factors which influence the production of suckers:- 1. Season. If the season be favorable there will be more suckers, with dry season there will be less suckers. 2. Fertility of the soil. If the soil be very rich and richly manured there will be more development of suckers than with a moderately manured soil. 3. Planting. In corn which is listed there will be fewer suckers than when surface planted. This may be due to the fact that listed corn gets a slower start at the early part of the season, and therefore develops fewer suckers. 4. Heredity. It has been experimentally proved by Hartley[2] that the offspring of parents possessing suckers had 14½ percent. of

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[1] De Vries: Plant Breeding, p.146.

[2] U.S. Dept. Agri. Year Book 1909.

suckers, while the offspring of parents possessing no suckers had but 2½ percent. of suckers. It is therefore safe to say that great increase of sucker is due to breeding from parents possessing suckers, and this habit being heredity can be controlled by breeding.

Economic Value of Suckers: Some agronomists have noted the economic value of suckers. Lyon[1] says they have a value in that they thicken up a deficient stand of corn and when well-developed produce ears. Moreover plants with suckers generally give larger yield than plants without suckers. Removing suckers has a tendency to decrease the yield, and this effect may be due to some physiological disturbance. Montgomery[2] found an average decrease of yields in three years when the suckers were removed. In regions of sufficient rainfall, it would not seem advisable to remove the suckers in the hope of improving the yield, this being due to the fact that ground gets loose as soon as it is wet, and on removing sucker the main stalk may fall over and thus lessen the yield.

2. FARMERS' BREEDING BLOCK.

It will not be possible for every farmer to breed corn on a large scale, but every farmer should improve the greater part of his own seed, no matter whether he does it on a large or very small scale. For a breeder, situated as the ordinary farmer, a

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[1] Nebraska Bulletin 91.

[2] Nebraska Bulletin 112.

simple and inexpensive method must be followed.

As we have said elsewhere, the farmer should select the best seed as it is ripening in the field and from the standing plants rather than from crib or wagon. He should not start with shelled corn which may contain many mixed and impure seeds. A breeding plot may be started with twenty or thirty of the choicest ears, planting them in a block by themselves on the side of the field from which the prevailing winds are likely to come, and removed at least one-quarter mile from any other variety. If corn of some other variety is too close the ears selected may be planted in the middle of the regular field. By thus surrounding it, and being crossed more or less with the ordinary field stock they are of course placed at a disadvantage. When planted on one side of the field it is better to plant in a block than in a long narrow strip, as some of the rows on one side are almost certain to get too little pollen of its own kind for complete fertilization. The field should be uniform in manuring and cultivation. The shelled seed of the thirty selected ears will be sufficient to plant from two to three acres. Before planting, the seed should be put under germination test. Selection should be based upon those germinating best and earliest. The plot whould be laid off by a marker into checks corresponding to the ordinary distance between rows and hills used in planting. The planting should be done by hand. Every precaution should be taken to plant uniform number of kernels and also to thin to uniform number of stalks, or else the tests would not mean anything. Here also all weak, or barren stalks should be detasseled.

During the growing season careful observation should be made of the growth of each row, and various field notes should be recorded. The breeder can use his judgment here in deciding what notes seem to be most important in his case.

Second year's work. Propagation Plot - the same as described on page 65. (Note: A repetition of steps of first year should be carried also in the second year).

Third year's work. Commercial Plot - the same as described on page 65. Here the farmer will secure his well-bred seed for the market.

3. THE BLOCK OR MATING SYSTEM.

In the block system an ear possessing prominent merit in one or more desirable characters is mated with an ear possessing other desirable characters, but perhaps somewhat inadequate in those points in which its mate surpasses. By this sort of mating the breeder tries to combine the desirable feature of both parents in the hybrid.

In practicing this system the odd numbered rows are planted with the odd numbered ears. When the tassel comes out the offspring of one ear is detasseled to prevent in-breeding, and the breeding ears for the following year's crop are selected from the detasseled rows.

It is to be observed here as well as in all row tests that the condition of soil may have more to do in the estimation of yields than the quality of the seed sown, even though the field [illegible] be uniform. In the plot system the soil is more important factor

in estimating the yields than it is in the row system, because the plots being small the soil will very likely be not representative of the entire field. Of course, if the plots are not isolated the progeny of the detasseled rows will not be entirely the result of crossing between the mated parents, but will largely be the result of crossing from stalks in near-by fields.

4. BREEDING TO IMPROVE CHEMICAL CONSTITUENT.

The writer has mentioned in the introduction the many different uses of the corn plant, and in Chapter IV the reasons for which one should breed corn. All these facts may certainly be considered sufficient reason to improve the chemical constituents, protein, fat, or carbohydrates of seed corn.

Hopkins and his associates[1] have made a thorough study of the structure and the composition of the different parts of the corn kernel, with a view to working out practical methods of selecting seed with reference to composition. There are six distinctly different parts in a kernel of corn, as will be readily observed by reference to Fig. 17 which are known as (1) the tip cap, (2) the hull, (3) the horny gluten, (4) the horny starch, (5) the white starch, (6) germ.

(1). The tip cap covers the tip end of kernel and comprises only about 1.5 percent of the grain.

(2) The hull is the very thin outer cover. It comprises about 6 percent. of the kernel and contains about 4 percent. protein.

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[1] Illinois Bulletin 87.

(3) The horny glutenous part (aleurone layer) lies underneath the hull. It comprises from 8 to 14 percent. of the grain, and it contains from 20 to 25 percent of protein, being the richest in protein of any part of the corn kernel.

(4) The horny starchy part lies next to the horny gluten, in the sides and back of the kernel (the germ face being considered the front of the kernel). It comprises about 45 percent. of ordinary corn, but is much more abundant in high-protein corn and less abundant in low protein. Although rich in starch, it contains about 10 percent. of protein (more in the high protein corn and less in low protein corn).It holds a greater total amount of protein than any other part of the kernel.

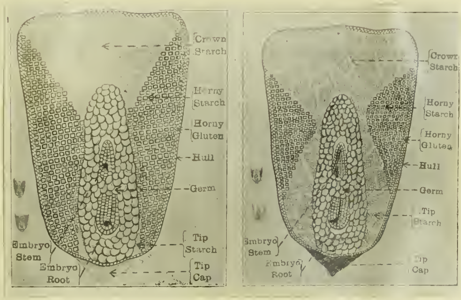
Crown Starch
Horny Starch
Horny Gluten
Hull
Germ
Tip Starch
Tip Cap
Embryo Stem
Embryo Root
Crown Starch
Horny Starch
Horny Gluten
Hull
Germ
Tip Starch
Tip Cap
Embryo Stem
Embryo Root

Fig. 17. Low-protein (on right) and high-protein (on left) corn kernels. (After Hopkins).

(5). The white starchy part occupies the center of the crown end of the kernel and nearly surrounds the germ. It comprises about 25 percent. of the kernel (less in high protein corn and more in low protein corn.) It is poor in protein,(5 to 8 per

cent).

(6). The germ occupies the center of the front of the kernel toward the tip end. It comprises about 11 percent. of the kernel (more in high oil corn and less in low oil corn). The germ contains from 35 to 40 percent. of corn oil, or from 80 to 85 percent. of the total oil content of the corn kernel.

There are two methods of breeding corn for chemical constituent:-

a. Chemical Selection by Mechanical Examination.

After removing a few average kernels from the corn, and soaking if hard, in hot water for fifteen or twenty minutes, then by the use of a small sharp knife two or three of these kernels are cut into cross sections and two or three other kernels into longitudinal section; finally they are examined with the naked eye. In selecting seed ears for high protein content, those ears whose kernels show a small proportion of the white starch immediately adjoining or surrounding the germ are to be saved. In selecting corn for low protein content, a larger proportion of white starch surrounding the germ should be looked for. The white starch surrounding the germ toward the tip end of the kernel is a better index of the protein content than the starch in the crown end.[1]

In selecting seed ears for high oil content, those ears whose kernels show a large proportion of solid germ are to be saved; while in selecting seed of low oil content, a small proportion of germ in the kernel should be looked for.

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[1] Illinois Bulletin 82, p. 531.

In this way a variety which is satisfactory should be selected for breeding for special composition. This chemical selection of seed ears by mechanical examination, has been very successfully used at the Illinois Experiment Station and by practical farmers. It is generally suited to the farmers who in general are not chemists and can not be chemists and who are obliged to breed their seed corn with very limited service.

b. Chemical Selection by Chemical Anaylsis.

In selecting seed corn by chemical analysis two neighboring rows of kernels as a representative sample are removed from each individual ear. "This sample is ground and analyzed as completely as may be necessary to enable in deciding whether the ear is suitable for seed for the particular kind of corn which it is desired to breed. Dry matter is always determined in order to reduce all other determinations to the strictly uniform and comparable water-free basis. If, for example, we desire to change only the protein content, then protein is determined. If we are breeding to change both the protein and the oil, then determinations of both of these constituents must be made"[1].

The above two methods of chemical selection are based upon the following two facts:- "(1) That the ear of corn is appromimately uniform throughout in the chemical composition of its kernels. (2) That there is a wide variation in the chemical composition of different ears, even of the same variety of corn"[2].

With these two facts established a working basis for the

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[1] Illinois Bulletin 82, p. 532.

[2] Illinois Bulletin 82.

chemical selection of seed corn was made. Breeding was started for four different purposes, namely; (1) for increase of protein content, (2) for decrease of protein content, (3) for increase of oil content, (4) for decrease of oil content. The experiments were started in 1896 with a variety of white corn locally known as Burr's White.[1] From the 1896 crop of this variety grown upon the Illinois Experiment Station, 163 best ears for seed were selected. From each ear a sample consisting of three rows of kernels lengthwise of the ear was taken for chemical analysis. The results of these analyses show great variation in the relative proportions of the various constituents. "The ash varies from 1.10 to 1.74 percent., the protein from 8.25 to 13.87 percent., the oil from 3.84 to 6.02 percent.,and the carbohydrates from 78.92 to 85.70 percent." According to these variations there were taken from the 163 ears four groups - (1) Twenty-four ears whose percentage of protein was comparatively high, (2) twelve ears each of which contained a low percentage of protein, (3) twenty-four ears high in oil content, (4) twelve ears low in oil content.[2]

The ears thus selected for the several purposes were planted in isolated plots by the well-known ear-to-row method and were continually selected within these same four groups by analysis of individual ears till the present time. The results obtained in these four directions are shown in the following tables which will give a good general view of the progress of the work:

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[1] This name was used in the records of Illinois Experiment Station until 1903, when it was decided to change the name to "Illinois".

[2] Illinois Bulletin 128.

Table IV

Increase and decrease of protein[1].

	High Protein Plot average in crop harvested.	Low Protein Plot average in crop harvested.	Difference between crops.
Year	Per cent.	Per cent.	Per cent.
1896	10.92	10.02	0.00
1897	11.10	10.55	0.55
1898	11.05	10.55	0.50
1899	11.46	9.86	1.60
1900	12.32	9.34	2.98
1901	14.12	10.04	4.08
1902	12.34	8.22	4.12
1903	13.04	8,62	4.42
1904	15.03	9.27	5.76
1905	14.72	8.57	6.15
1906	14.26	8.64	5.62
1907	13.89	7.32	6.57
1908	13.94	8.96	4.98
1909	13.41	7.65	5.76
1910	14.87	8.25	6.62

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[1] American Breeders Magazine, Vol. I No. 1, p.16.

Table V

Increase and decrease of oil.[1]

	High Oil plot average in crop harvested.	Low Oil plot average in crop harvested.	Difference between crops.
Year	Per cent.	Per cent.	Per cent.
1896	4.70	4.70	00.00
1897	4.73	4.06	0.67
1898	5.15	3.99	1.16
1899	5.64	3.82	1.82
1900	6.12	3.57	2.55
1901	6.09	3.43	2.66
1902	6.41	3.02	3.39
1903	6.50	2.97	3.53
1904	6.97	2.89	4.08
1905	7.29	2.58	4.71
1906	7.37	2.66	4.71
1907	7.43	2.59	4.84
1908	7.19	2.39	4.80
1909	7.05	2.35	4.70
1910	7.72	2.11	5.61

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[1] American Breeders Magazine, Vol. I, No. 1, p. 17.

We see from the above figures that there has been a great variation both in protein and oil content in fourteen generations; starting with a variety of average composition the high protein content varied from 10.92 to 14.87 per cent, and the low protein varied from 10.02 to 8.25 percent. The high oil content varied from 4.70 to 7.72 percent and the low oil content varied from 4.70 to 2.11 per cent. In other words there has been possible to produce out of a single variety, two strains of corn, one of which contains almost twice as much protein as the other, and two other strains have been produced, one of which contains now nearly three times as much oil as the other.

We see further that in spite of selecting from the highest protein content of the preceding year there was no gain in the years 1898,1902,1905,1906,1907 and 1909. It seems to have lost a little ground in this high protein breeding. A glance at the low protein column enables us to see the similar irregularities. There was no gain in 1897,1898, 1901,1903,1904,1906,1908, and 1910.

We notice further that in some seasons the protein content was very high, and in some seasons it was extremely low; this is due to the climatic conditions of the season upon the composition of the crop. Smith[1] says that "a lack of moisture tends to increase the proportion of protein and abundance of moisture reduces it, due, of course, to the effect of water supply upon carbohydrate formation," and this fact is true"in irrigation experiments where it has been observed that the quantity of water supply has a direct influence upon the composition of corn, wheat, and oats, the protein content of the grain decreasing as the water supply in-

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[1] Illinois Bulletin 128.

creases."

The results of breeding to influence the oil content has been even more regular and more uniform than that for protein as indicated by the changes from year to year. There has been constant increase of oil content in the high oil plot except in 1901, 1908,1909. Similarly there has been steady decrease of oil content in the low oil plot with but one exception, namely, in 1906. Here also this difference may be explained to some peculiar seasonal or soil conditions. Perhaps certain seasons were favorable to the production of oil, while other seasons were normal or unfavorable in this respect. There is another striking result as to be seen in the column of the differences in percentage between the two crops and that is that after ten years the difference 4.71 remained stationery. The highest high oil and the lowest low oil occured in 1910 when the record was broken wonderfully; it is also important to notice that the greatest difference between the high- and low-protein was 6.62 which also occured in the same year; this year must have had the advantage of exceedingly favorable season.

These extensive experiments show clearly the progress resulting through contirued selection. Shull[1] in his recent article explains these experiments by saying that "here selections for high oil content, low oil content, high protein,and low protein . .. . . have all led to the production of strains which possessed the desired qualities to a much higher degree than that in which they existed in the foundation stock when the selection began. All of these results may be readily explained on the ground that some hybrid combinations of genotypes have greater capacity for the production of the desired qualities than other combinations,

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[1] American Naturalist, Vol. XLV No. 532.

and that the selection has gradually brought about the segregation of these genotype-combinations which had the highest capacity for the production of the desired qualities".

Other selections to influence chemical constituents are reported by the Kansas and Nebraska Experiment Stations. In 1898 an experiment was started at Kansas to increase the nitrogen content, and concluded with the crop of 1901 when the highest nitrogen content was obtained. The authors of Kansas Experiment Station Bulletin No. 107 say that the nitrogen content can be increased by continuous selection of kernels possessing relatively large germs.

At Nebraska, selections were made to influence the chemical constituents, the experiment was continued for three years; some gain was made in the selection for high oil[1].

Breeding to Increase the Sugar Content.

That Indian corn can produce "as much true glucose, ton for ton and acre per acre, as the sugar cane crop grown in Louisana", is shown by Stewart, as mentioned by Gill. His theory is that since the maize plant, botanically, belongs to the same family as the sugar cane and contains a fair amount of glucose in its normal condition, it might be increased to such an extent that the profitable manufacture of cane sugar would become economically possible. The method depends on the physiological phenomena that if the ears be removed from the stalk at a certain time before the plant stops growing, it would keep growing from four to six weeks beyond its

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[1] Nebraska Bulletin 91.

natural life time. Not only the plant is increased in size and vigor but the sugar content is increased to more than double its normal quantity, with a purity far above that of the natural juice.[1]

Experiments have been made in twenty different stages to verify Stewart's process. The following table is typical of the average results obtained from analyses which show the progressive stages of accumulation of sugar in the juice from the beginning to the close of the stage of its saccharine development:-

Table VI[2]

	Before Sterilization.			After Sterilization.			
	Tassel Developing.	In Silk	Grain in Milk	One Week	Two Weeks	Four Weeks	Six Weeks
Sp. gr.	1.0126	1.034	1.048	1.050	1.058	1.069	1.075
Glucose percent.	0.000	2.90	6.70	9.78	11.09	13.79	14.66
Reducing sugar	1.87	3.00	2.50	1.90	1.47	1.11	1.79
Combining sugar	1.87	5.90	9.20	11.60	12.56	14.90	16.45
S. N. S.	1.13	2.80	1.80	1.80	1.44	1.90	1.92
Total Solids	3.00	8.70	11.00	13.40	13.90	16.80	18.37
Co. of purity		33.3	60.9	72.3	79.7	82.4	79.8

The above figures show great increase of sugar content at six weeks.

Later on, Doby made further experiment according to Stewart's directions. He reports that in his experiments, the cane sugar content rose considerably after removal of the unripe ear, then it began to decrease gradually. He says'this is probably due

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[1] American Sugar Industry and Beet Sugar Gazette, January '10.
[2] American Sugar Industry and Beet Sugar Gazette, January '10.

to the fact that the leaves after drying cease to assimilate, while the still living stalk respires a certain amount of the sugar. This circumstance must be taken into account in fixing the date of the harvest.' In such experiments the rise and fall of sugar content is possible, such differences are influenced by climatic conditions; if the weather be damp and cool, the growth will be retarded, and with the coming of the fall season vegetation may stop, whereby the further accumulation of sugar will be hindered.[1]

Stewart also emphasized that the manufacture of paper pulp from the fibrous portion of the plant and alcohol from the green ears can be carried out better for domestic comsumption than ever has been done and all at much less cost. In United States the ordinary value of corn per acre is now $12.00 net; and if the farmers and breeders increase the sugar content and make the best utilization of various parts of the corn by the Stewart method, the value of the corn crop could be raised to at least $32.00 net.

5.BREEDING TO IMPROVE PHYSICAL CHARACTERS.

Corn is a plant whose development can easily be directed. Among the various lines of investigation to improve the physical characters of this plant many interesting results have been accomplished by continuous selection in various directions.

The purpose to increase the number of rows in the ear of a corn was first started by Mueller.[2] He selected ears with the greatest number of rows for sowing; the commonest were those,

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[1] American Sugar Industry and Beet Sugar Gazette, February'11.

[2] Kosmos, 1886, Vol. II p.22.

with 10 to 12 rows. Among many thousands of ears, he found a single one with 18, but none with 20 rows. After three years continuous selection the mean shifted to 16 rows, while single ears had as many as 26 rows. De Vries[1] repeated this experiment. He sowed seeds from ears with 16,20,24, 22 rows during 1886 to 1894. In 1897 he started with 20 rows, his mean was 20 rows per ear. One can increase the number of rows in this way, but whether he will get good seeds with a greater number of rows is doubtful. De Vries' ears with a greater number of rows had poor seeds and produced smaller kernels.

In 1898 Card started experiments with the intention to increase the number of ears per stalk by selecting from year to year with that end in view. Selection from that time until 1904 was carried on in two different lines: (1) Selection from lower ears, (2) Selection from upper ears. A steady increase of number of ears was observed in every year from selecting seed from the upper ears. In the season of 1902 not only the ears but the average number of stalks per hill was greater on the plot and the young plants were more vigorous, and of better color when grown from seed selected from upper ears than from seed chosen from lower ears. Card says that this was largely due to the stronger vitality and higher germinating power of the seed taken from upper ears, since these were not poorly developed like low ears. In the season of 1905 the selection was made only from the upper ears, and the results showed that the average number of ears per stalks were 3.90, the highest number from several stalks being thirteen. Moreover, those plants which produced thirteen ears gave an average

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[1] De Vries: The Mutation Theory, Vol. I pp.71-73,1909.

total yield of 43.4 ounces per plant or nearly five times the average yield of the unimproved crop.[1] In corn where the yield is the main consideration, it will be a good idea to breed corn so as to increase the number of ears per plant, and this physical character was practically influenced as shown by Card by selection from upper ears.

Another character that has likewise responded in a striking manner to seed selection is the height at which the ear is borne upon the stalk. In the season of 1902 from an ordinary field of Leaming corn Hopkins selected two sets of ears, one of which represented ears growing high on the stalk and the other, those borne low down on the stalk. These two sets of ears were planted the following season in separate breeding plots at the Illinois Experiment Station, and selection for high and low ears from that time has been carried out each year since. An outline of the results is shown in the following table:-

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[1] Rhode Island Bulletin 116.

Table VII

Breeding for High Ears and Low Ears[1]
(Average height in inches)

Year	High ear Plot	Low Ear Plot	Difference
1903	56.4	42.8	13.6
1904	50.3	38.3	12.0
1905	63.3	41.6	21.7
1906	56.6	25.5	31.1
1907	72.4	33.2	39.2
1908	57.3	23.1	34.2
1909	64.3	25.3	39.0
1910	69.0	27.0	42.0

In looking over these figures we find the highest high ear was obtained in 1907 and the lowest low ear was obtained in 1908 which has never surpassed since that time. It will also be noticed that in some years instead of an increase there appeared to be a slight regression. This is likely to be due to very unfavorable seasonal conditions. During the last three years the average height of ears in the one strain is more than twice that in the other, This as in the case of the composition of the grain, illustrates the shifting of the types by selection. Perhaps the importance of these results is most strikingly shown in the fact that two strains of corn have been produced, in one of which the ears are now borne about three feet higher on the stalk than in the other strain.

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[1] American Breeders Magazine, Vol. I No. 1, p.19.

There are two factors which have been involved to influence the height of ears; namely, the number of internodes and the average length of each internode. Incidentally, at selection time, as Smith says plants having longer internodes and bearing their ears at a higher node, were selected for high ears while in the case of low ears the reverse of this has taken place. As to the effect on maturity and yield he reports that the lower ear plot matures earlier than high-ear plot, and that the yields from these two strains are thus far about equal.[1]

According to Card[2], as the writer has mentioned before "lower ears are often poorly developed". That is, one would infer from his statement that for getting a good stand, the use of upper ears is preferable. But Smith points out that "early maturity is characterized by few and short internodes with fruit borne low" and that this principle applied not only to his own experiment on corn, but it also holds true for other crops. For example, it was found in breeding cotton in southern states and peas at the Swalöf Plant Breeding Station[3]. His results also agree with the observation of Fruwirth and Sturtevant. Chamberlain whom the writer has quoted before in page 29, also advises to select low ears when early maturity is desired. From all these facts, the writer thinks that Card's theory is either not correct or else perhaps it is not of universal application.

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[1] Illinois Bulletin 132.

[2] Rhode Island Bulletin 116. p. 35.

[3] Illinois Bulletin 132.

Another interesting character which is influenced in a striking manner by seed selection is the declination of the ear[1] at the time of maturity. Smith[2] selected two sets of ears in 1903,"erect" and "declining" ears from the"Illinois High-oil" breeding plot. These he planted in two corresponding breeding plots and selection has been carried out in these two directions since that time. These plots have been conducted on the same general system as the "High-ear" and "Low-ear"plots, planting by the ear to row method, detasseling alternate rows and basing the first selection upon the yield of individual rows.

When the corn is ripe, an index having a movable pointer and a half circle marked off in degrees is used in measuring the angle of declination. The data is taken on the plants at certain definite intervals in everyrow, so that the results will represent a fair average. "If the ear stands erect the angle is recorded as 0, if horizontal it is 90 degrees, if hanging straight downward it is 180 degrees, and all intermediate positions are recorded in degrees corresponding"[3].

The general results of this work are shown in the following table:-

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[1] This refers to the angle which the ear makes with the stalk.

[2] Illinois Bulletin 132.

[3] Illinois Bulletin 132.

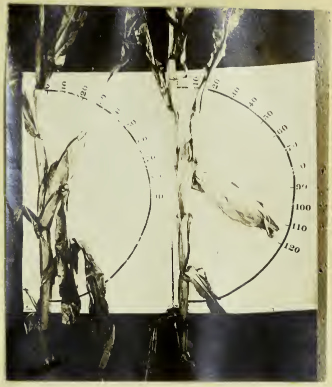

Fig. 18. After six generations the average angle of declination in the erect-ear strain is 31.2 degrees. In the declining-ear strain it is 110.7 degrees.
(After Smith).

Table VIII

Breeding for Erect and Declining Ears[1].
(Average angle of declination fron stalk)

Year	Erect Ear Plot	Declining Ear Plot	Difference
1904	42.0	45.0	3.0
1905	62.2	117.1	54.9
1906	49.5	76.2	26.7
1907	42.3	81.6	39.3
1908	46.0	88.5	42.5
1909	31.2	110.7	79.5

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[1] American Breeders Magazine, Vol. I, No. 1, p.20.

We see from the above results that in the first generation the difference between the two strains was very slight. In the second generation there was a great response to the selection. After that the difference has steadily increased and has reached now almost 80 degrees. This experiment clearly indicates that the declining habit has been influenced by breeding.

The question may arise: What will be the advantage of "declining ears"over"erect ears"? The practical advantages are found in the better protection from rain and consequently less chance of becoming rotten or mouldy and also the greater convenience in handling at harvest.[1]

6. PURE-LINE BREEDING. - A NEW THEORY.

By a"pure-line" here we mean all the offspring of a single plant, the mode of reproduction being self-fertilization. Johannsen with beans and barley, and Jennings with protozoa demonstrated this mode of reproduction, and the theory of pure-line is a well-established hypothesis. The question may arise: What good will come out of this mode of reproduction with Indian corn, where in-breeding causes deterioration as has been pointed out in the previous discussion? In answer to this question Shull recently brought out a new theory. He says :" I have been able to deomnstrate, however, that this supposedly injurious effect of self-fertilization is only apparent and not real; or at least that if

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[1] Illinois Bulletin 132.

there is such injurious effect, it is relatively insignificant as compared with the increased vigor due to heterozygosis. The most important evidence of this is found in the fact that the continuation of self-fertilization in any pedigree does not produce a corresponding decrease in vitality and size. The decrease resulting from a second year of self-fertilization is not as great as that from the first year. The third year of self-fertilization produces still less deterioration, and as this process is continued a limit is approached in such manner as to justify the inference that when complete purity is attained no further deterioration is to be expected, thus proving that self-fertilization is not in itself injurious"[1].

In his first paper Shull gives the description of an experiment in which he had one row of corn produced from a self-fertilized ear having 14 rows of kernels, and another row produced from a self-fertilized ear having 14 rows. In each row, slight variability was observed. Most of the characters differed more or less in both cases from the cross-fertilized rows derived from the original stock. Shull says:" If self-fertilization is assumed to be the direct cause of any of the above characteristics of the one row, it is obviously illogical to attribute the opposite characteristic possessed by the other row to self-fertilization as a direct result". He comes to the conclusion that these differences are not directly attributable to seff-fertilization, but must be due to an indirect effect. "The distinguishing characters of these two rows are permanent inheritable qualities and each therefore represents what is known as elementary species

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[1] American Naturalist, Vol. XLV, No. 532.

or biotype, as Johannsen has appropriately named the elementary form-group. Self-fertilization has simply isolated the two described forms by separating them from their hybrid combinations with other elementary species"[1].

Another theory pointed out by this author is that 'crosses between nearly related types (in both animals and plants) are usually more vigorous than either of the parent types alone.' In-breeding in corn tends to isolate biotypes; and these by themselves generally appear to be inferior to the naturally cross-bred ones. East[2] corroborates the latter part of this argument. He says, "If there is a deterioration directly due to in-breeding under the old hypothesis, continued in-breeding should have brought about further degeneration. By the present theory when once the biotype has been extracted, no further deterioration will take place, provided the plant is not diseased and its environment is normal". He cites Darwin's several experiments such as with Petunia violacea and Minulus luteus, and points out clearly that with continued self-fertilization there is no accumulation of detrimental characters.

Another suggestion of Shull is to breed two uniform but distinct types, and obtain the best results by hybridizing them each season. This is of a great theoretical importance and therefore worthy of trial, even though such a method should not prove practical.

Let us study how the pure-line method in corn breeding

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[1] Proceedings A. B.A. Vol. IV.

[2] Bein. Report of Conneticut Agri. Experiment Station(1907-08)

as devised by Shull[1] is applied. The method may be considered under two heads: (1) Finding the pure-lines; and (2) The practical use of the pure-lines in the production of seed corn.

(1) The best pure-lines can be obtained by the self-fertilization of many strains which should be continued season after season until the homozygous state is nearly reached. Then all possible hybrids are to be made by crossing these various pure strains and the plants of the first generation coming from each such hybrid are to be put to the ear-to-row test, each row being the product of a different hybrid. Full records as to the yield and the possession of other desirable characters of these cross-bred rows should be kept. The breeder can make any sort of combination best suited to his purpose according to market or other conditions. Thus, if the in-bred strains be represented by the letters of the alphabet, it may be found that the cross P x H will give 100 bushels per acre of high-oil corn, that B x D gives a similar yield of high-protein corn accompanied by high yield, and so on.

(2) When the right pairs of pure strains have been found for the attainment of any desired purpose, two isolated plots as shown here will be necessary: In Plot I, only the best and pure mother-strain which was obtained by investigation will be grown year after year. Thus, if it has been found that the cross P x H gives the desired result, strain P will be planted in Plot 1.

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[1] Proceedings A. B. A. Vol. V, 57-59.

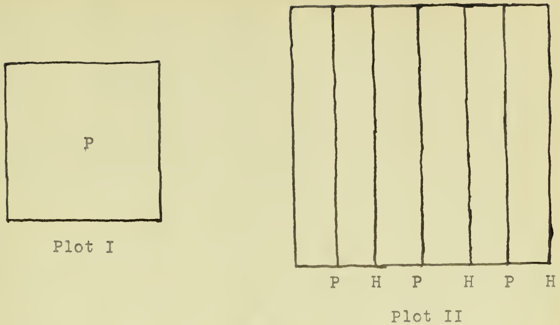

Fig. 19. Arrangement of the two Isolated Plots for the Pure-line Method of Corn Breeding. (After Shull).

All exceptionally vigorous or aberrant individuals found should be discarded as being probably due to the entrance of foreign pollen. Strain P and H are to be planted in Plot II in alternate rows as shown in the diagram, here all of the strain P is to be detasseled. Seed-corn for the general field-crop will be picked from the detasseled rows, and those that are picked only from the tasseled rows will be pure-bred strain H to be used again the following year in the same way. Here again in pure strain H all exceptionally vigorous or aberrant individuals, if found, should be eliminated.

This pure-line method seems to be simpler than those now in use at the Illinois and Ohio Experiment Stations, and if it were tested out by the breeders it might result in the discovery of one of the best possible methods for the breeding of corn. At present we do not see any difficulty in accepting this method except it would be more expensive than breeding by the present method on which account perhaps it will not be best suited to the farmers.

CHAPTER VII

FUTURE OUTLOOK OF IMPROVING SEED CORN.

The statistics made by the United States Department of Agriculture and as compiled by Hopkins[1] from the Year Books show that "the average annual production of corn in the United States increased during this ten-year period from 2,074 million to 2,733 million bushel; the average exportation of corn from the United States decreased from 177 million to 67 million bushels. Consequently the annual supply of corn for domestic use increased from 1897 million to 2,666 million bushels - an increase of 40 percent". Such an increase over the whole country would mean an increase in national wealth of about $384,500,000 each year, allowing fifty cents per bushel as an average price. This increase is due to planting more acres and also raising more corn on the same acreage by improved methods of farming in which good breeding must have taken a very important part.

The demand for well-bred seed is very strong all over the corn growing states. Williams of the Ohio Experiment Station writes: "The farmers are very anxious to purchase seed from the station; more anxious than we are to sell. The few farmers who are taking the trouble to produce pedigreed corn are finding ready sale for it at good prices"[2]. Further as to this matter Hughes

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[1] Science, N.S. Vol. XXIII, No. 846. March 17, 1911.

[2] Quoted from private letter received by the writer.

of the Iowa Experiment Station writes: "There is a pretty large demand for good seed corn in this state, but again there are probably more men who have good seed for sale than in a large number of states in the corn belt"[1]. In order to meet all such demands first, the further development of railways and other means of rapid transportation should be made; second, the further improvement of corn should be accomplished by planting well-bred seed of the best germinative qualities; third, making still further improvement of the progenies of these plants season after season. Many of the American farmers buy seed in the market without any knowledge of its history or excellence trusting entirely to luck for it to produce the desired crop. Such seed is generally contaminated, and hence not desirable for improvement. The best remedy here is to buy seed either from his neighbor, if he be a grower of well-bred seed, or direct from the seed farms, where it is made a business of producing well-bred seed.

There has been already established such farms in many parts of the corn belt. From Illinois, Funk Brothers' seed farm is worthy to be mentioned here. Much of this work depends on the hands of the farmers who are graduates of the agricultural college and the writer has already heard that some of his colleagues have established seed-breeding farms and are progressing well. The State Experiment Stations exhibit the samples of well-bred seeds, but all do not distribute and sell their seeds. It is practically impossible for a State Experiment Station to provide any consider-

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[1] Quoted from private letter received by the writer.

able number of farmers with well-bred seed from the land belonging to the main experiment station. This is for several reasons: (1) Because of the fact that many stations have not sufficient appropriation to start a regular business of supplying well-bred seed to the farmers. (2) Because of the fact that seed grown at the main station will not be equally adapted to all portions of the state. For these reasons it is exceedingly important to establish other seed distributing farms remote from the State Experiment Station from which seed can be delivered direct to farmers in those districts. The main object of the Experiment Station is to show to the farmers the principles of raising well-bred seed, and it is the duty of the farmers to come into touch with the operation of the station and apply such principles on their own farms.

There are some experiment stations where the surplus well-bred seeds are not sold at all. To them the writer's question is: What good will come out of the production of such seed corn if not to be distributed or sold to the farmers? The Directors of such stations themselves may answer this question.

The future outlook of improving seed corn is bright, and it is only in the beginning of its development. The "Seed Corn Special train" of Iowa and Indiana, the "Better-farming Special" of Virginia, the "Seed and Soil Special" of Illihois, have made thousands and thousands of farmers realize necessity of improving their seed corn. All such movements have created great enthusiasm amongst the old as well as the young. We may hope that the seed-breeding will be the vocation for many such listeners and will receive far more attention than heretofore.

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